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Quirien van Oirschot

Storability of sweet potatoes (*Ipomoea batatas* (L.)) under tropical conditions: physiological and sensory aspects

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Abstract

The shelf-life of the sweet potato storage root under tropical marketing conditions limits its potential for marketing. This research aimed to identify the physiological characteristics that affect the shelf-life of sweet potato cultivars when they are exposed to tropical marketing conditions.

Weight loss was the key limiting factor in storability under the conditions studied. The range in weight loss was large amongst the 39 cultivars tested, and varied between 5 to 15% per week. Weight loss related to the marketable appearance. It consisted mainly of water loss and only 10% was due to respiratory metabolism. Sweet potatoes with high rates of water loss were more susceptible to rotting.

The role of periderm characteristics (thickness and permeability), root-size, root surface area/mass ratio and shape were investigated. Although significant differences were observed among cultivars, these characteristics could not account for the variation in storability.

The level of damage severely affected the rates of weight loss, with transpiration rate through damaged areas many times higher than through undamaged periderm. Breakage was found to be the most severe form of damage, having a great impact on weight loss for 14 days. Cultivars differed in susceptibility to damage after standardised damage treatments. Susceptibility to breaks was greater for long thin roots. Skinning injury was negatively related to the periderm thickness.

Wound healing ability was a major factor for the shelf-life of sweet potato cultivars. It was demonstrated that lignification of wounds as measured by phloroglucinol staining, correlates with reduced susceptibility to weight loss, water loss and microbial attack. A lignin index was used to express the probability that lignification occurs. Cultivars differed significantly in their lignin indices under tropical marketing conditions. A high dry matter content generally coincided with a low lignin index. This relationship was consistent for 19 cultivars tested.

Sensory evaluation of five sweet potato cultivars resulted in five distinct sensory profiles. During storage some of the cultivars lost some of their flavour but little changes were observed for textural properties. It was concluded that changes in sensory aspects are not a limiting factor for storage of sweet potato.

Acknowledgements

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List of Abbreviations

ARTI = Agricultural Research and Training Institute

CIP = International Potato Center

GET = Germplasm Evaluation Trial

KARI = Kenyan Agricultural research Institute

NARL = Nairobi Agricultural Research Laboratories

NRI = Natural Resources Institute

UYT = Uniform Yield Trial

Technical terms

DM = Dry Matter content

LI = Lignification Index

LSD = Least Significant Difference

PG = Phloroglucinol

RH = relative humidity

T = Temperature (°C)

Chapter 1

Introduction and Background

A large proportion of the population in the tropics relies on various root crops as a source of starchy food. Although these crops rarely appear on the world markets and are not cultivated on a large scale, they are of immense importance locally. They are constituents of the daily diet and, when cereals are in short supply, provide the sole source of starch. They are high yielding crops and cheap to produce. Sweet potato (*Ipomoea batatas* (Lam)) is one of these root crops (Gomes, 1996).

Sweet potato has many agronomic advantages: It is easy to grow and requires relatively low maintenance. It is relatively resistant to diseases and drought, and the energy produced per unit area is amongst the highest of starch staple crops. Sweet potato produces approximately 2.1 tonne dry matter per ha which translates into 152 mega joule·ha^{-1}·day^{-1} (Minde *et al.,* 1998). In addition, growth of sweet potato is considered to be beneficial for sustainability of livelihoods, because its rapid coverage of the ground reduces soil erosion (Westby, 1999). Despite all these advantages, the potential of sweet potato is still under-exploited.

Historically sweet potato received little attention in crop improvement programmes and hence the number of scientific publications found for sweet potato is relatively limited. A literature search in CAB Abstracts, resulted in 5,874 publications for sweet potato, which is the smallest number of the 10 most major crops, followed by cassava (7,352).

Table 1.1 Top ranking of food crops for edible energy*, world annual production and the number of publication titles found in CAB-Abstracts (1972-1999)**

Crop		Energy ha^{-1} day^{-1} (mega joule)*	Production (million tonnes)**	Number of titles CAB Abstracts (1972-1999)
Wheat	*Triticum aestivum*	135	530	127,711
Rice	*Oryzae stativa*	151	478	84,463
Maize	*Zae mays*	159	456	118,655
Potato	*Solanum tubersoum*	216	317	54,729
Barley	*Hordeum vulgare*		175	57,510
Cassava	*Manihot esculenta*	121	131	7,352
Sweet Potato	*Ipomea batatas*	152	119	5,874
Soybeans	*Glycine max*		91	27,154
Sorghum	*Sorghum bicolor*		73	29,693
Bananas and plantains	*Musa*		62	8,727
Tomatoes	*Lycopersicon esculentum*		60	39,824

* *Data sourced from Minde et al., (1998).*

** *Data sourced from Woolfe (1992) derived from FAO data.*

This situation is now being remedied by the inclusion of sweet potato in the programmes of international research organisations such as the International Potato Center (CIP). It is believed that sweet potato could play an increasing role in food security and income generation in Southern and East Africa (Westby, 1999; Van Otterdijk, 1998). With increasing urbanisation (8% per year in Dar es Salaam) the provision of food to urban centres is of growing importance. While programmes in the 1970's tended to concentrate especially on yield improvements, the emphasis is now shifting to post harvest related aspects, including the potential for commercialisation, processing and product development (Moyo *et al.*, 1998).

In the tropics sweet potato is highly perishable, and under tropical marketing conditions the shelf-life can be as short as one week (Thomson *et al.,* 1996; Jana, 1982). This is in contrast with the situation in the United States where sweet potatoes can be kept for up to a year (Picha, 1986b). The perishability increases the risk for farmers and traders. Although farmers and traders have adapted their practices to the perishable nature of the commodity, for example by piece meal harvesting, trading of low quantities and transportation over short distances, the perishability forms a major constraint for the increase of production and commercialisation (Van Otterdijk, 1998; Fowler and Stabrawa, 1993).

If the shelf-life of sweet potato could be increased, this would benefit its marketability and transport. Extension of shelf-life would increase the flexibility to trade and market the crop. As a result the production would increase. This thesis investigates the physiological nature of perishability and storability of sweet potatoes when they are exposed to tropical marketing conditions.

1.1 Sweet potato; general information

1.1.1 History

Sweet potato originated in Central America or north-western South America. Its entry into cultivation probably occurred about 3000 B.C. The ancient Peruvian and Mayan civilisations of tropical America grew sweet potatoes extensively. The introduction of sweet potato to Africa, Asia and North America occurred in the 16th and 17th centuries by Spanish and Portuguese explorers and traders (Onwueme, 1978). There are however reports that the introduction of sweet potato to Polynesia occurred long before that, but when and by whom is not yet clear (Woolfe, 1992).

1.1.2 Botany and cultivation

Sweet potato is a dicotyledonous plant belonging to the Convulvulaceae family. A large number of sweet potato cultivars exists and the number is larger than for most other tropical root crops. Cultivars have arisen through systematic breeding as well as natural

hybridization and mutations. In East Africa alone, 2000 clones have been identified in the past (Jana, 1982).

Sweet potatoes are grown from 40°N to 32°S of the equator. On the equator they are grown from sea level to 3000 m. Growth is best at or above 24°C and when temperatures fall below 10°C it is severely retarded. The crop is damaged by frost and this restricts its cultivation in temperate regions to areas with a minimum frost free period of 4 to 6 months (Onwueme, 1978).

It should be noted that the storage organ of the sweet potato is a true root. This is in contrast to potatoes, which are tubers originated from the stem (Kays, 1985).

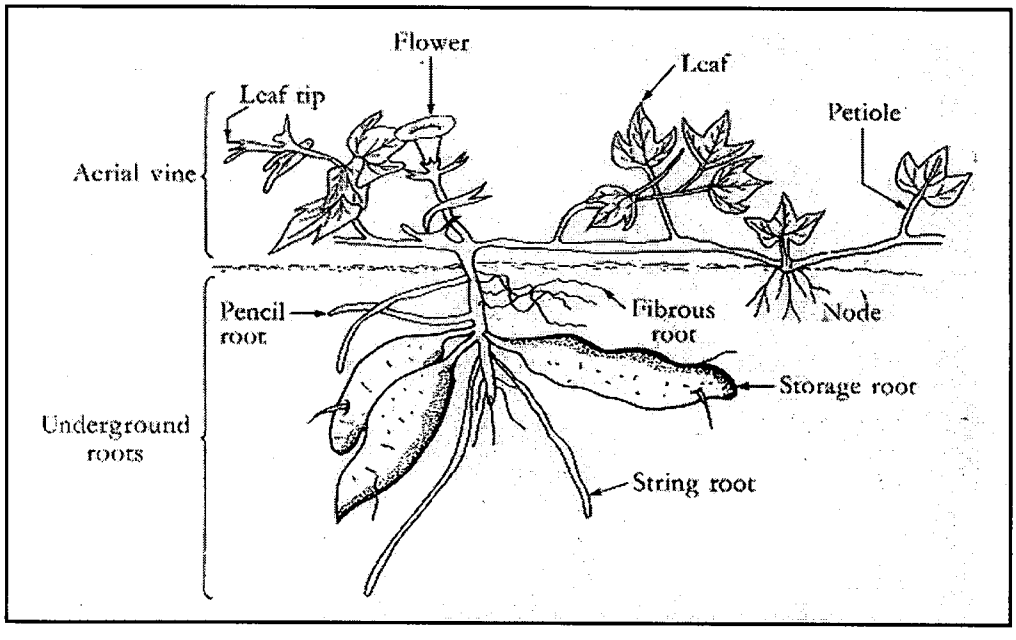


Figure 1.1 Morphology of the sweet potato plant. In practice, the proportion of foliage to root is somewhat greater than that shown here.
(Sourced from Woolfe, 1992)

Sweet potato is a perennial plant, but it is normally grown as an annual. Under cultivation it is usually propagated from vine cuttings. The growth occurs in three more or less distinct phases. In the first phase fibrous roots grow extensively and there is only moderate growth of vines. In the second phase the vines grow, the leaf area increases and the growth of storage roots is initiated. In the third phase the bulking of the storage roots takes place (Kays, 1985).

Sweet potato storage roots are ready to harvest after 4 to 5 months, but sometimes depending on the cultivar, this can be longer. The number of storage roots produced per plant varies but is generally from 3 to 10 roots (Woolfe, 1992).

1.2 Sweet potato post harvest

1.2.1 Curing and storage

In temperate regions, sweet potatoes are kept for periods of 6 months or longer (Picha 1986b). Ideally the temperature during storage should be 15°C and the relative humidity 85% or higher. In the USA sweet potatoes are generally stored at the farms, in large warehouses. The roots are stored in large wooden boxes (Plate 1.1).

The roots are normally cured before storage. Curing allows damaged areas to heal. Ideal curing conditions are at temperatures between 26 to 28°C, and at a relative humidity of at least 85% (Kushman and Wright, 1969). During curing a lignified layer is produced under the ruptured tissue, after which a wound periderm is formed. This effectively reduces moisture loss and prevents micro-organisms from entering (Artschwager and Starrett, 1931, Weimer and Harter, 1921).

In the tropics sweet potatoes are not commonly stored. In East Africa farmers conduct in ground storage, and harvest when they need to. This is called piece meal harvesting. In the ground the roots can be prone to attack by insect pests, rodents and disease. However, several studies have proved that storage of sweet potatoes under tropical conditions is possible for up to 5 or 8 months. In Malawi successful storage was conducted in pits and huts using humidified dambo sand to retain the high humidity. Dambo sand contains organic matter, nitrogen, potasium, phosphorus, zinc, calcium and magnesium, and has a high pH (Sandifolo *et al.*, 1998).

Pit and clamp storage of sweet potatoes was successfully conducted in Uganda. Pits and clamps (Plate 1.2) were lined with grass, and the roots were kept successfully for up to 5 months (Hall, 1998; NRI/NARO, 1996).

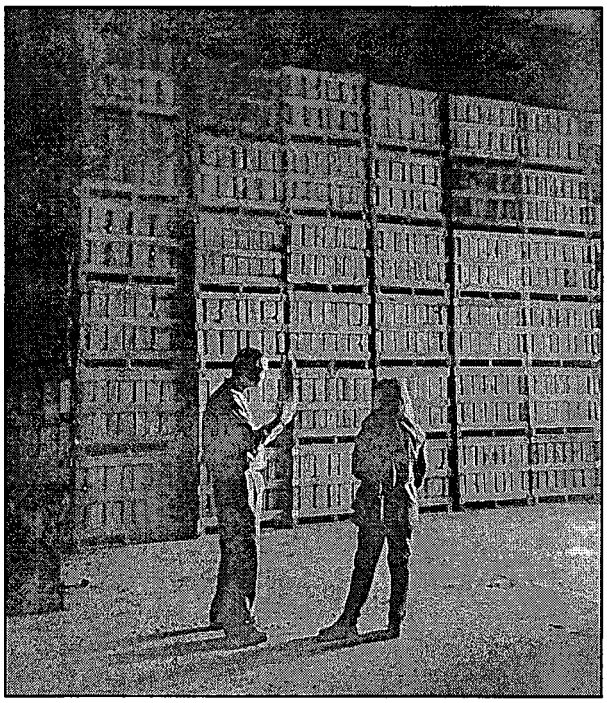


Plate 1.1 Sweet potato storage warehouse in the United States

Plate 1.2 Construction of a sweet potato storage clamp in Uganda
(Sourced from NRI/NARO, 1996)

As the normal temperature and relative humidity in the tropics are very similar to those required for curing, natural curing often does occur. Jenkins (1982) reported that curing sweet potatoes artificially before storage under tropical conditions did not have any additional beneficial effects. Both cured and uncured roots showed nearly 20% weight loss after 5 weeks of storage. Gull and Duarte (1974) however showed that simple techniques, such as lining storage crates with plastic, results in lower weight loss during storage and a higher percentage of marketable roots.

1.2.2 Sweet potato marketing in East Africa

Sweet potato is mainly used for home consumption in East Africa. Hence the marketing systems to date are poorly developed. Reports from Uganda estimated that only 20% is being marketed (Fowler and Stabrawa, 1993) and in Zambia this was only 13% (Van Otterdijk, 1998).

It is important to consider the traditional practices of handling and marketing of sweet potatoes in East Africa because any improvement of shelf-life and storability will need to occur under these conditions. The following paragraphs will give a description of the sweet potato marketing and handling practices in the Lake Zone in Tanzania.

The Lake Zone is the region around Mwanza, and is an important sweet potato production area (Figure 1.2). After harvest sweet potatoes are normally transported from the farm to the road by bicycle or handcart. At the road side they are then re-packed (Plate 1.3b), and transported to the market by truck or light vehicle. Traditionally the sweet potato roots are packed in woven polypropylene sacks, each weighing between 70 and 200 kg. Farmers force as many roots into a sack as possible. Firstly because the transport costs of the roots are paid per sack, and secondly because traders and wholesalers would demand a discount if the quantity is less. The sacks are usually not large enough to accept the required volume of roots and hence a 'head of roots' is built to the sack by wrapping roots in sweet potato vines and strings (Plate 1.3c). This form of packing probably increases damage during transport, even though grass or vines are sometimes used to protect the produce during transportation (Tomlins *et al.*, 1999a; Thomson *et al.*, 1997).

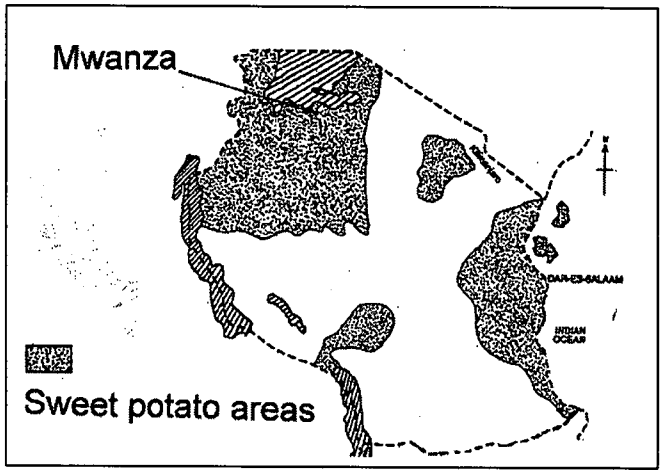


Figure 1.2 Main sweet potato cultivation areas in Tanzania.

At the market the sweet potatoes are sold by retailers, who sell the produce in heaps. Retailers sometimes wash the sweet potatoes to make them more visually attractive. The sweet potatoes are displayed in heaps and in open sacks during the day. The roots are often displayed uncovered so that the customers can see the sweet potatoes from afar. At the end of the day the sweet potatoes are covered with sacking, stored under market tables or put back into the sacks. A large percentage (91%) is normally sold within two days of arrival (Thomson *et al.*, 1997).

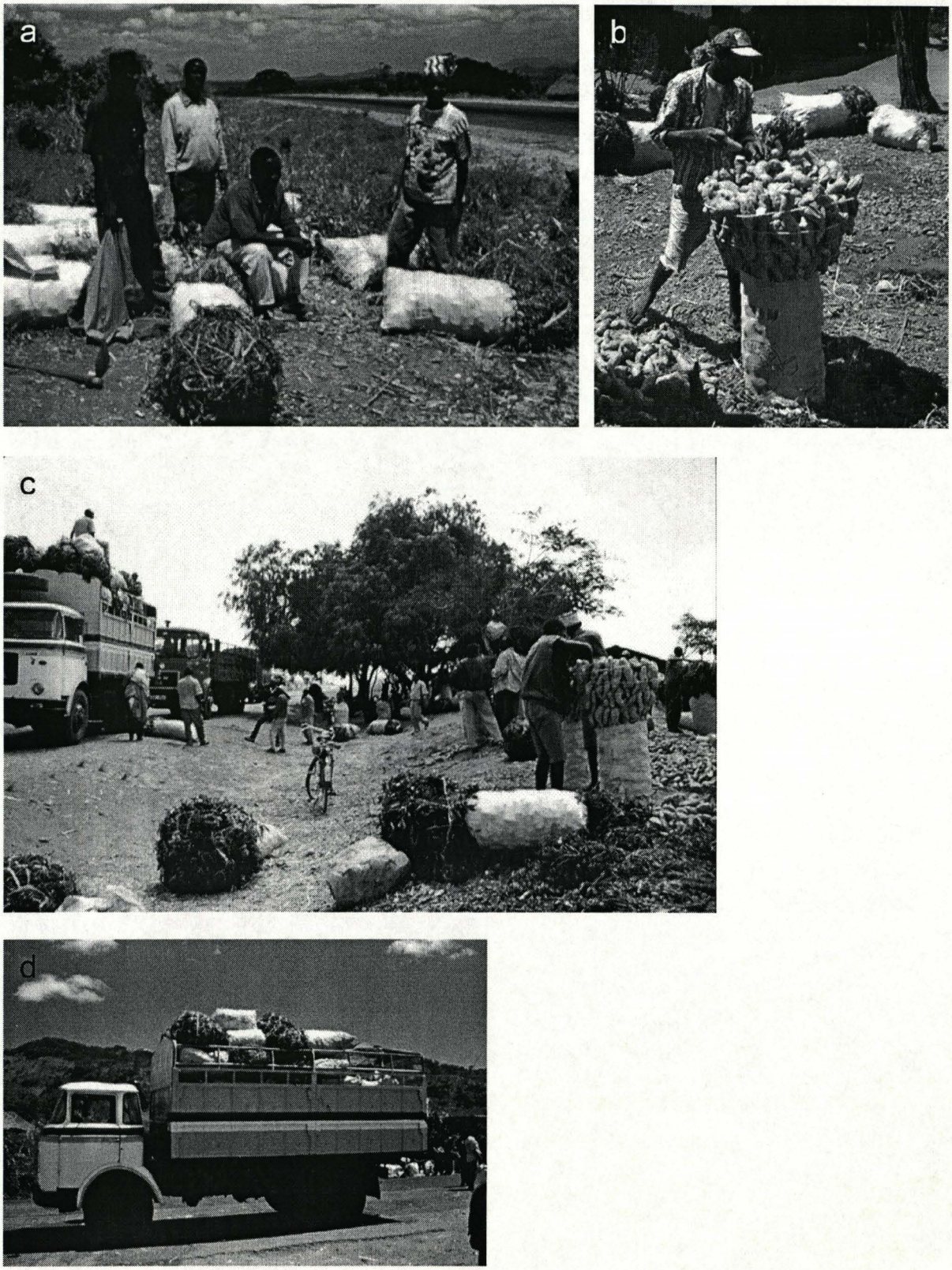


Plate 1.3 **Handling of sweet potatoes after harvesting. a) sweet potatoes after harvesting. b) repacking sweet potatoes before transport; c) loading sweet potatoes on the lorry; d) sweet potatoes during transport.** ***(Photos from Debbie Rees)***

1.2.3 Economic importance of improving shelf-life and storability

Storability: for household use

Sweet potato production is often limited to wet seasons. In East Africa roots should be harvested at the beginning of the dry season as if the roots are left in the ground they will be prone to attack by weevils (*cylas* spp) which reach the roots through soil cracks. To serve as a food security crop through the dry season the roots are often processed into dried products. However insect infestation is often a problem after 3 months. If roots could be stored fresh for several months, even before processing, this could enhance the potential for food security (Hall, 1998)

Storage of sweet potatoes would benefit farmers in an additional way. Roots could be harvested as soon as they mature so that the land could be made available for other crops. The incidence of pest and disease attack in the field could be significantly reduced. Good quality stored roots could also act as an emergency source of income by marketing during the dry season when fresh roots are no longer available in the field.

Shelf-life: for marketing

Another very important issue is the shelf-life of the roots during the process of marketing. As said above the perishable nature of sweet potato in East Africa is a fundamental constraint for marketing. It makes marketing inflexible and restricts farmers and traders in their ability to respond to unpredictable markets. There is a risk of seasonal oversupply that leads to substantial losses if the roots are not transported and marketed immediately following harvest. This risk is translated into additional marketing costs (Fowler and Stabrawa, 1993). This limits distances and quantities that can be marketed.

The results from a market study in Zambia illustrate the constraints of transport and perishability. Only 48% of the farmers sell sweet potato. Per household an average of 450 kg is sold per year, giving a meagre revenue of 38 dollars. Most of the crop is sold at home (46%), 16% on the road, and 24% at the local market. 42% was sold at distant markets. About 73% is sold to consumers directly, 38% to retailers, and 15% to wholesalers. A significantly lower price was gained from selling to wholesalers, 0.05 US dollar/kg, compared to 0.08 US dollar/kg for sale to consumers and retailers (Van Otterdijk, 1998).

1.2.4 Perishability of sweet potato

Sweet potato roots are living organisms and as such are unavoidably subject to losses during their autonomous life when the root has been separated from the plant. This is because the life process requires energy and the root has to supply this from its own reserves.

The post-harvest physiological processes that may affect storability include the following, all of which are influenced by the storage conditions:

a. Respiration;
b. Evaporation of water from the product.
c. Sprouting;
d. Changes in chemical composition;
e. Diseases
f. Damage by extreme temperatures;

(Rastovski, 1987).

The relative importance of these processes differs with the storage conditions. Under tropical conditions high temperatures are likely to result in high rates of respiration. Increased rates of metabolic breakdown could result in increased levels of weight loss (Wills *et al.,* 1998). The evaporation of water is directly related to relative humidity and water vapour pressure deficit (Wills *et al.,* 1998). Although the relative humidity in the tropics is frequently high, for uncovered roots during marketing it can be sufficiently low to allow rapid water loss through the skin surface.

Rotting is a problem for sweet potato. The most important post-harvest diseases of sweet potato are Rhizopus soft rot, which is caused by *Rhizopus stolonifer* or *Rhizopus oryzae* and Java black rot, caused by *Botryodipldia theobromae.* Also Fusarium root rot, caused by *Fusarium solani*, bacterial root rot by *Erwinia chrysanthemi* and black rot caused by *Ceratocystis fimbriata* can be a problem (Clark, 1992)

Although the literature refers to constraints of perishability in sweet potato, there is little detail of the specific limiting factors of perishability.

1.3 Objectives of this thesis

The research reported here is part of a larger project that has as its aim the extension of shelf-life and improvement of quality of the sweet potato crop in East Africa.

The work described in this thesis relates to physiological characteristics that determine the storability of sweet potatoes. The work was conducted in collaboration with the International Potato Center (CIP) in Nairobi, Kenya, and the Agricultural Research and Training Institute (ARTI) at Ukriguru, Mwanza, Tanzania.

The storability of sweet potatoes is inevitably affected by many factors. For example storage losses can be physiological or pathological. But although pathological losses can be considerable, this PhD focuses on the physiological aspects only. The objective of this research were as follows:

Objectives of this PhD:

- To identify the characteristics that limit shelf-life of sweet potatoes under tropical conditions and determine the relative importance.
- To determine the range in storability that exists among germplasm available in East Africa.
- To investigate the basis of cultivar differences in storability

1.4 Outline of this thesis

The thesis is composed of 8 Chapters. Figure 1.3. gives an overview of the steps taken during the research indicating the main topics addressed per chapter.

Chapter 1 comprises this introduction and refers to the importance of improvement of shelf-life to reach its full potential in the tropics and it also identifies the research objectives of this thesis. Chapter 2 gives information on the storage trials, the conditions and storage set up.

Chapter 3 to 7 have been written as self contained chapters. Each chapter comprises its own introduction, a short review of relevant literature, materials and methods, the results and discussion and a summary of findings and conclusions.

In Chapter 3 the role of weight loss is determined and the storability of 39 sweet potato cultivars is evaluated.

Chapters 4 to 6 are focused towards elucidating why cultivars differ in rates of weight loss. Chapter 4 considers the contribution of root size and characteristics of the native periderm. Chapter 5 examines the role of damage in weight loss and investigates the susceptibility to damage. Chapter 6 comprises the role of wound healing, its efficiency, and how it relates to the dry matter content of the storage root.

Chapter 7 evaluates the changes of sensory properties during storage and the extent to which these aspects could limit shelf-life.

In Chapter 8 a general discussion with the main conclusions and recommendations for future research is presented.

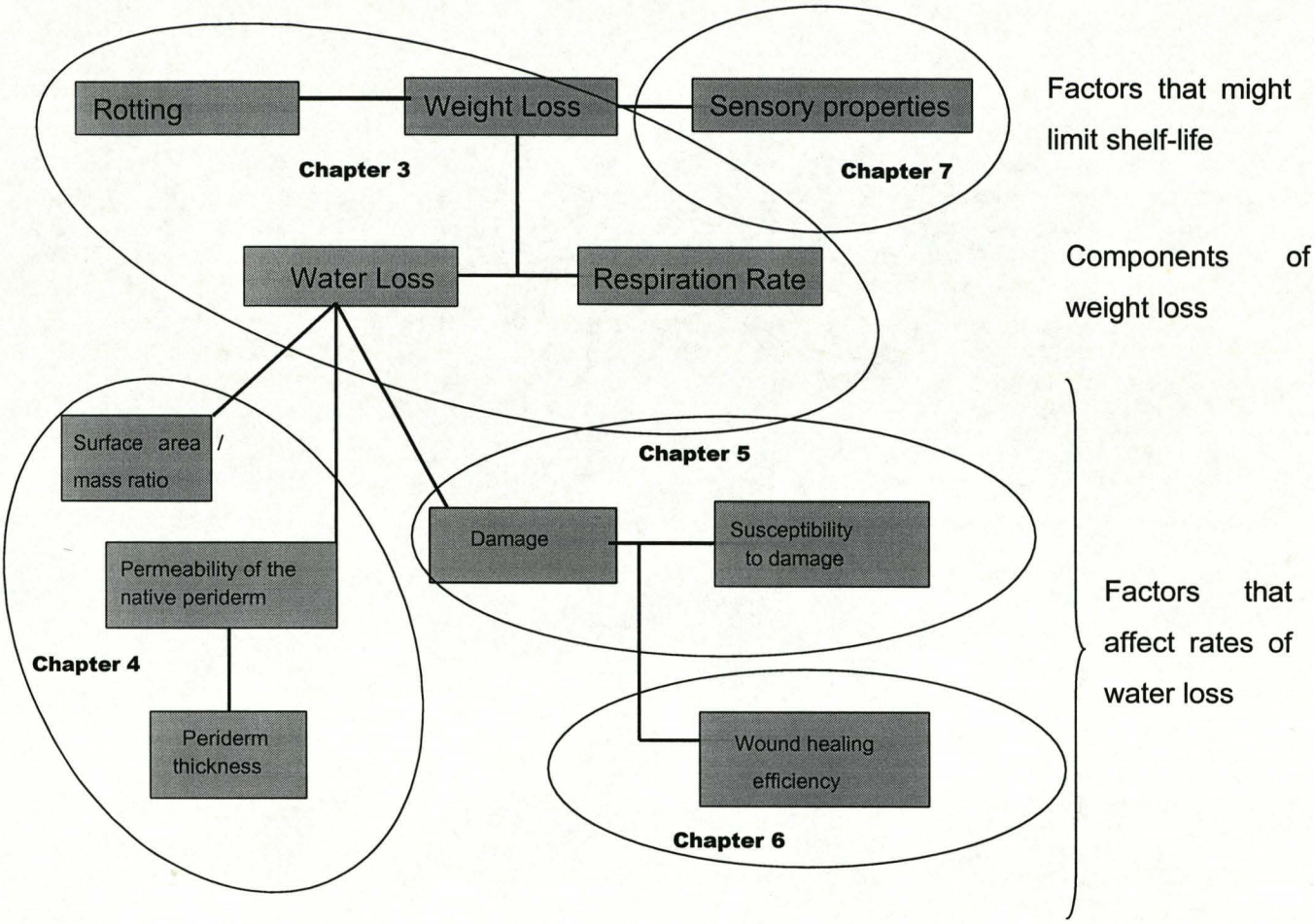


Figure 1.3 An overview of the chapters in this thesis, investigating the factors that affect the storability of sweet potatoes under tropical conditions

Chapter 2

Design of field and storage trials

2.1 Introduction

The work described in this thesis covers data collected from fourteen post-harvest trials carried out in the UK, Kenya and Tanzania. In this chapter details are given about the cultivars, the location and lay-out of the field trials used to provide plant material design and conditions of the post-harvest trials. The specific methods to assess storability are described in subsequent chapters.

The roots for the storage trials were grown in two locations: the Agricultural Research and Training Institute (ARTI) in Ukiriguru, Mwanza, Tanzania and by the International Potato Center (CIP), Nairobi, Kenya, using the fields of the University of Nairobi, Kabete fields, Nairobi, Kenya.

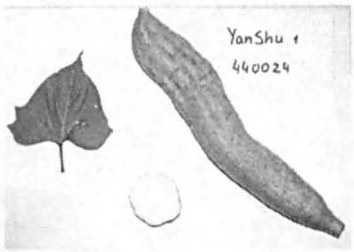
The storage trials were conducted at the following locations: ARTI in Ukiriguru, Mwanza, Tanzania, NARL – KARI, Nairobi, Kenya, NRI, Chatham Maritime, UK.
For the trials conducted at NRI in Chatham the sweet potato roots were grown in Kenya and airfreighted to the UK. To avoid chilling injury during this transport the roots were kept in a temperature controlled hold.

2.2 Cultivars

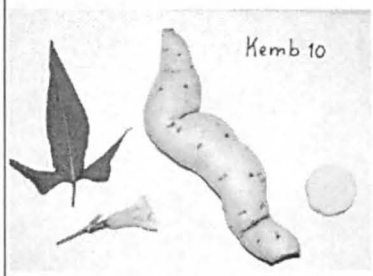
The sweet potato cultivars used in the trials are listed in Table 2.1 and illustrated in Figure 2.1. Table 2.2 (at the end of this chapter) presents a summary of the cultivars used in each trial. In all cases cultivars were selected to provide a range of characteristics although it was also important that they were able to produce a reasonable yield.

Table 2.1 Overview of all the cultivars used in the trials. The cultivars that performed best in the storage trials are underlined.

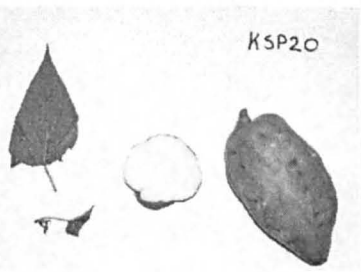
Sweet potato cultivars grown at CIP, Nairobi, Kenya			**Sweet potato cultivars grown at ARTI Ukiriguru, Tanzania**			
Name	**Corresponding CIP number**	**Origin**	**Name or number**	**Origin**		**Origin**
Yan Shu 1	440024	(Chinese)	440025	CIP	Luganza	
Kemb 10	440169	(East Africa)	440037	CIP	Lutambi	
KSP 20		IITA	440088	CIP	Nyamwisekeleya	
Zapallo (Pumpkin)	420027		440113	CIP	Polista	
SPK 004		(East Africa)	440121	CIP	Shinamugi	
BP1-SP-2	4440293		440215	CIP	SP/93/34	
Caplina	187016.1		Bagala		Tabu waseka	
Salyboro	187017.1		Bilagala		TIS 8250	IITA
Yarada	187018.1		Budagala		Tula Omushako	
Julian	440141		Budagala mpya		Mwanamonde	
Santa Amaro			Iboja		Sinia B	
Naveto			Ipembe		SPN/0	
Mugande			Itemve		SP/93/2	
NIS/94/340			Kagole		SP/93/23	
Sowole			Kombegi			
SPK013						
Potato cultivars	**(obtained from Kangemi market, Nairobi)**					
Kihoro						
Nyayo						



Yan Shu 1 (440024)



Kemb 10 (440169)



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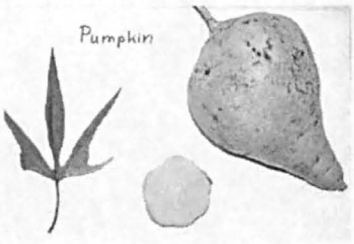
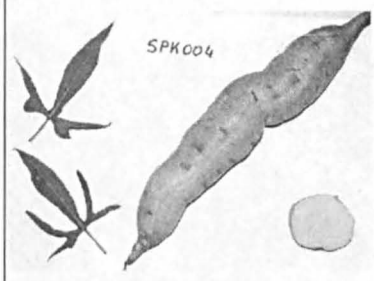
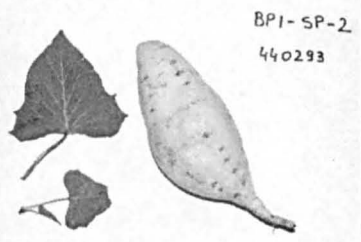


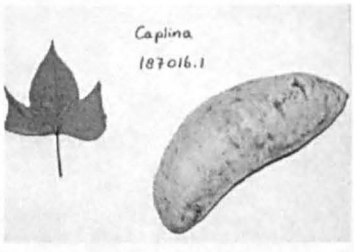
Zapallo (420027)



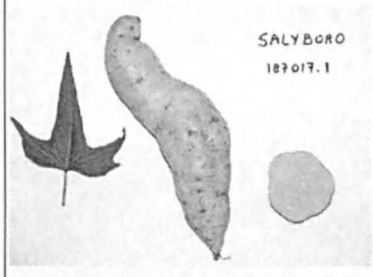
SPK 004



BP1-SP-2

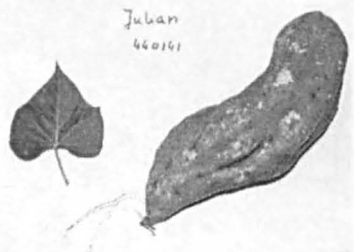


Caplina



Salyboro

Yarada



Julian

Figure 2.1a Typical shapes of sweet potato cultivars grown in Kenya

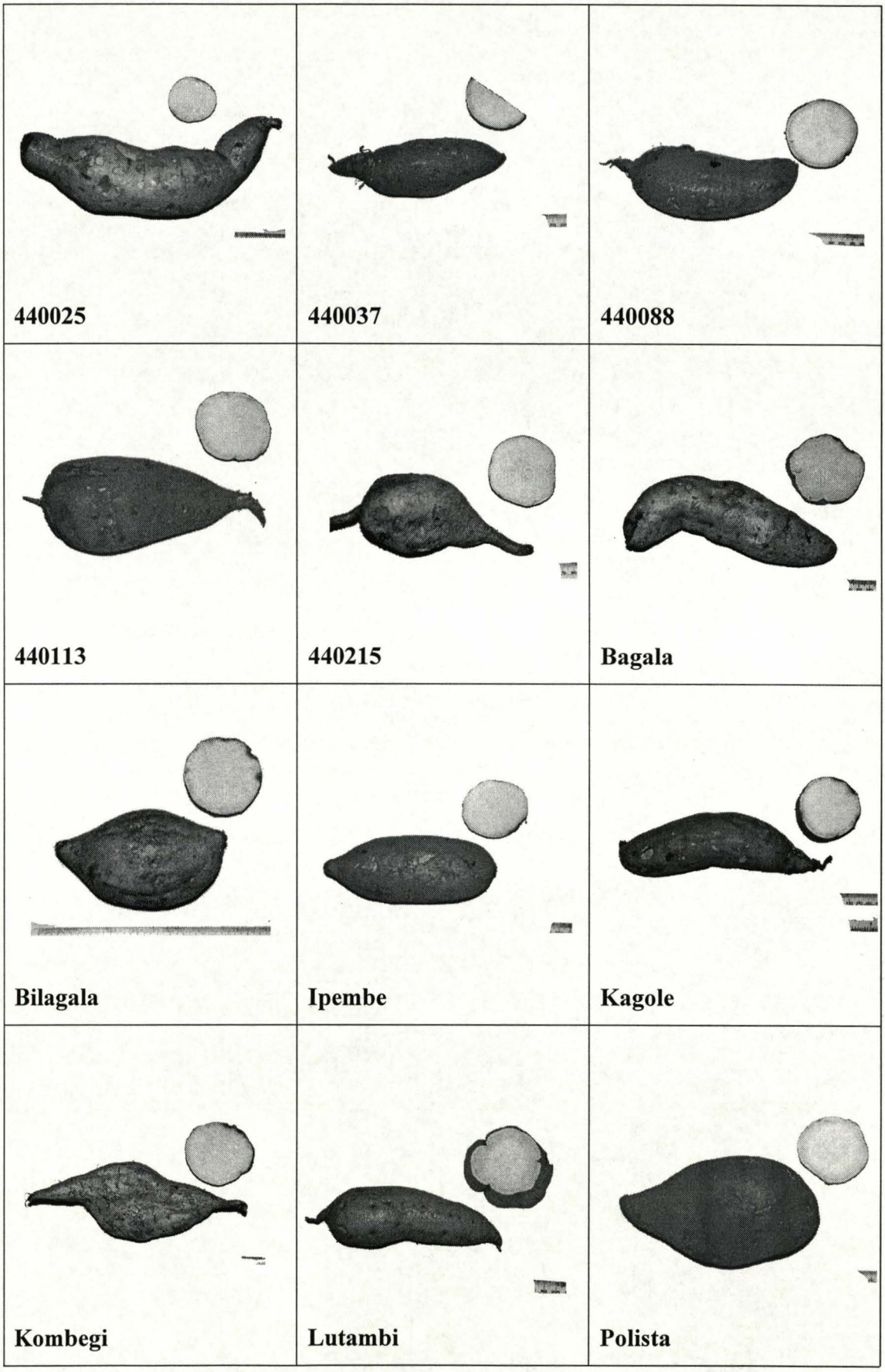


Figure 2.1 b Typical shapes of sweet potato cultivars grown in Tanzania

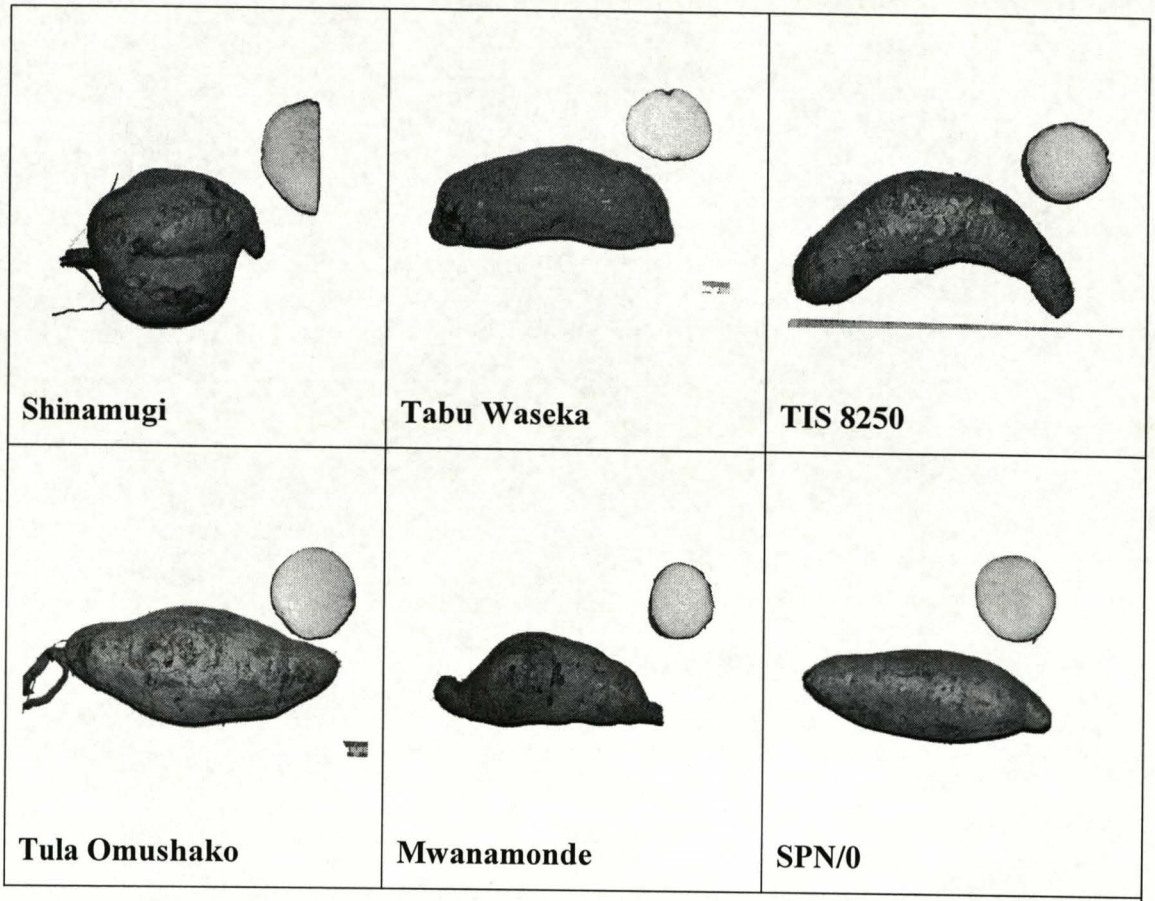


Figure 2.1 c Typical shapes of sweet potato cultivars grown in Tanzania

2.3 Field trials

Twelve trials were grown and harvested at Kabete, Nairobi, Kenya (Plate 2.1a) and three trials at the ARTI, Ukriguru, Mwanza, Tanzania (Plate 2.1b). The information for each of the field trials is given below, and a summary in Table 2.3.

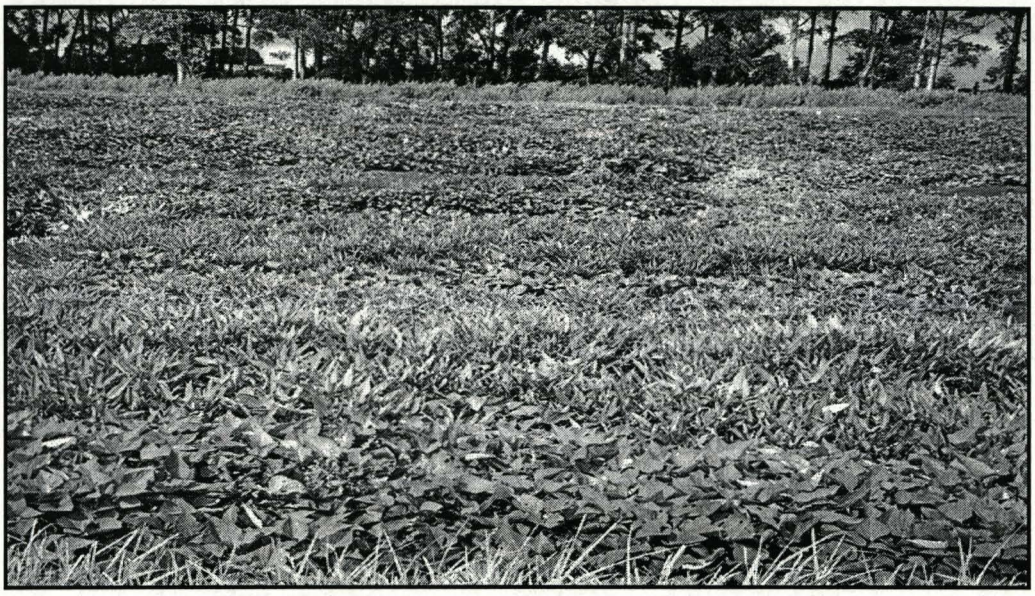


Plate 2.1a Field with 5 sweet potato cultivars, Kabete, Nairobi, Kenya

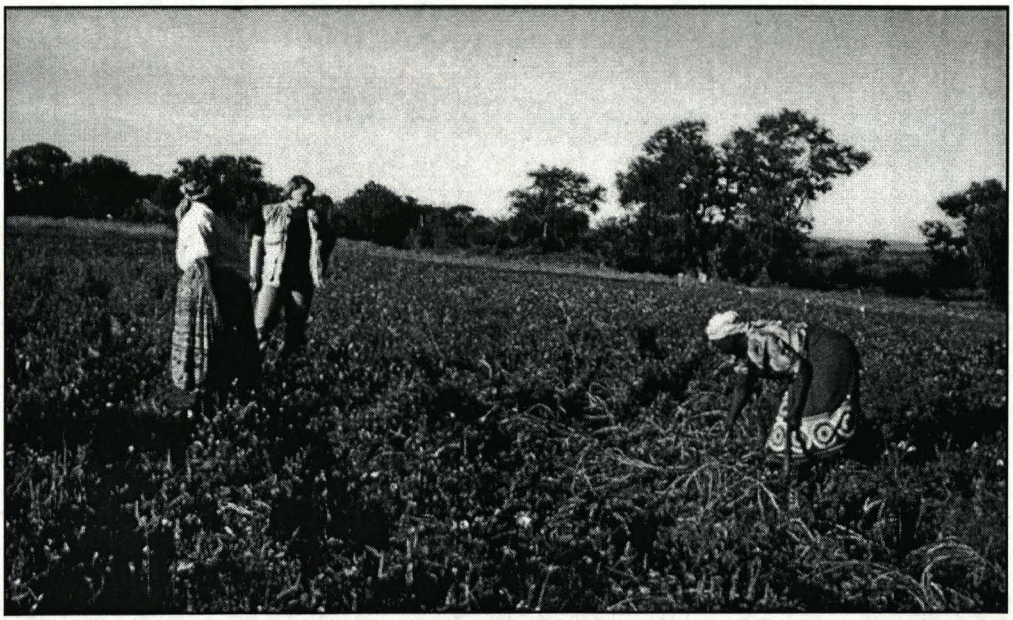


Plate 2.1b Harvesting sweet potato roots at ARTI, Ukiriguri, Tanzania

Trial 1

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004

Field design: No field replication

Planting date: 15th July 1996

Harvesting date: 22th January 1997

Treatment of roots between harvest and post harvest trial: washed, packed in cardboard boxes, cultivars separated by nets, airfreighted to the UK.

Trial 2

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004

Field design: No field replication

Planting date: 15th July 1996

Harvesting date: 15th March 1997

Treatment of roots between harvest and post harvest trial: washed, packed in cardboard boxes, cultivars separated by nets, airfreighted to the UK.

Trial 3

Location: ARTI, Ukiriguru, Mwanza, Tanzania

Cultivars: 440025, 440037, 440088, 440113, 440121, 440215, Bagala, Bilagala, Budagala, Budagala mpya, Iboja, Ipembe, Itemve, Kagole, Kombegi, Luganza, Lutambi, Nyamwisekeleya, Polista, Shinamugi, SP/93/34, Tabu waseka, TIS 8250, Tula Omushako, Mwanamonde, Sinia B, SPN/0, SP/93/2, SP/93/23

Field design: Complete Randomised Design

Germplasm Evaluation Trial (GET): 2 replicates, plots 6 m x 2 rows

Uniform Yield Trial (UYT): 4 replicates, plots 6 m x 6 rows (3 plants per m)

Planting date: 28th December 1996

Harvesting date: 23rd June 1997

Treatment of roots between harvest and post harvest trial: roots were used for yield assessment and weevil scoring before put under storage conditions.

Comments: Due to poor establishment extra cuttings were planted on 17th of January.

Trial 4:

Location: Farms, Iteja Region, Lake Zone, Tanzania

Cultivars: Mwanamonde, Sinia B, SPN/0, SP/93/2, SP/93/23

Field design: No field replication

Planting date: January 1997

Harvesting date: 7th July 1997

Treatment of roots between harvest and post harvest trial: transported in polythene bags from the field by car

Comments: These roots were bought from on-farm trials.

Trial 5 and 6:

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004

Field design: No field replication

Planting date: July 1997

Harvesting date: December 1997

Treatment of roots between harvest and post harvest trial: washed, packed in cardboard boxes, cultivars separated by nets, airfreighted to the UK.

Trial 7A and 7B:

Location: Kabete Nairobi Kenya

Cultivars: 7A: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004

7B: BP1-SP2, Caplina, Salyboro, Yarada, Julian

Field design: 7A:100 plants of each cultivar were planted in 2 or 3 rows, no replication, 7B: No replication

Planting date: 20th November 1997

Harvesting date: 28th of April 1998

Treatment of roots between harvest and post harvest trial: 7A: washed, 7Byield measurements carried out in the field, then washed.

Comments: 7A: Before harvest the field was divided into 3 replicates and 10 plants per rep were pruned on 21/4, one week before harvesting, leaving about 10 cm of the vines. Roots were harvested in replicates, using sticks instead of hoes (Plate 2.2).

7B: The cultivars, BP1-SP2, Caplina, Salyboro, Yarada, Julian, were harvested from another experiment which was also planted on the 20th November 1997and harvested on 28th of April 1998 and will be referred to as trial 7B. The roots were harvested by a different crew of local harvesters using hoes. As a result of the yield measurements in the field the roots were slightly more damaged than the roots of trial 7A.

Trial 8

Location: Kabete Nairobi Kenya

Cultivars: 7A: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004

Field design: 7A:100 plants of each cultivar were planted in 2 or 3 rows, no replication,

Planting date: 20th November 1997

Harvesting date: 12th May 1998

Treatment of roots between harvest and post harvest trial: washed

Trial 9:

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian, 2 potato cultivars: Nyaya and Kihoro.

Field design: Complete Randomised Design: plants were planted in 3 field replicates, each consisting of 4 rows x 10 plants for Yan Shu 1, Kemb10, KSP20, Zapallo and SPK004 and 3 rows of 10 plants for BP1-SP-2, Caplina, Salyboro, Yarada, Julian.

Planting date: 25th May 1998

Harvesting date: 27th October 1998

Treatment of roots between harvest and post harvest trial: washed

Comments: Harvested with hoes. The two potato cultivars (Kihoro, Nyaya) were obtained from Kangemi market, Nairobi.

Trial 10

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian.

Field design: Complete Randomised Design: plants were planted in 3 field replicates, each consisting of 4 rows x 10 plants for Yan Shu 1, Kemb10, KSP20, Zapallo and SPK004 and 3 rows of 10 plants for BP1-SP-2, Caplina, Salyboro, Yarada, Julian.

Planting date: 25th May 1998

Harvesting date: 4th November 1998

Treatment of roots between harvest and post harvest trial: Pruning treatments were carried out three plants per plot for the cultivars Yan Shu 1 (440042), Kemb 10, KSP 20, Zapallo (420027) and SPK 004. Dates of pruning: 23rd and 30th of October (1 and 2 weeks before harvesting). All roots were washed before the post-harvest trial.

Comments: Harvested with hoes.

Trial 11

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian, 2 potato cultivars: Nyaya and Kihoro.

11B: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian

Field design: 11: Complete Randomised Design: plants were planted in 3 field replicates, each consisting of 4 rows x 10 plants for Yan Shu 1, Kemb10, KSP20, Zapallo and SPK004 and 3 rows of 10 plants for BP1-SP-2, Caplina, Salyboro, Yarada, Julian.

11 B: From border rows

Planting date: 11: 25th May 1998

11B: July 1998

Harvesting date: 11: 11th November 1998

11B: 1st December, 1998

Treatment of roots between harvest and post harvest trial: washed

Comments: Roots were harvested with hoes. The two potato cultivars (Kihoro, Nyaya) were obtained from Kangemi market, Nairobi.

Trial 12B

Location: Kabete Nairobi Kenya

Cultivars: 12B: Santa Amaro, Mugande, SPK 013, NIS/94/320, Sowola, Naveto, KSP 20, Yan Shu 1.

Field design: Roots were obtained from another field trial, except Yan Shu 1, and KSP 20 which were obtained from trial 11B

Planting date: July 1998

Harvesting date: 1st December 1998

Treatment of roots between harvest and post harvest trial: washed

Comments: Roots were harvested with hoes. The two potato cultivars (Kihoro, Nyaya) were obtained from Kangemi market, Nairobi.

Trial 13 and 13B

Location: Kabete Nairobi Kenya

Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian, 2 potato cultivars: Nyaya and Kihoro.

Field design: 13: Border Rows, No field replication

13B: Complete Randomised Design: plants were planted in 3 field replicates, each consisting of 3 rows x 10 plants

Planting date: July 1998

Harvesting date: 13: 21st December 1998

13B: 7th January 1998

Treatment of roots between harvest and post harvest trial: washed

Comments: Some of the roots of trial 13B were of poor quality due to viral diseases.

Trial 14A and 14B

Location: 14A: Kabete Nairobi Kenya, 14B: ARTI, Ukiriguru, Mwanza, Tanzania

Cultivars: 14A:Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada, Julian

14B: Polista, SPN/0, SP/93/2

Field design: Complete Randomised Design: plants were planted in 3 field replicates, each consisting of 4 rows x 10 plants for Yan Shu 1, Kemb10, KSP20, Zapallo and SPK004 and 3 rows of 10 plants for BP1-SP-2, Caplina, Salyboro, Yarada, Julian.

Planting date: November 1998

Harvesting date: March 1999

Treatment of roots between harvest and post harvest trial: airfreight to the UK. Individual roots were wrapped in newspaper and packed in cardboard boxes

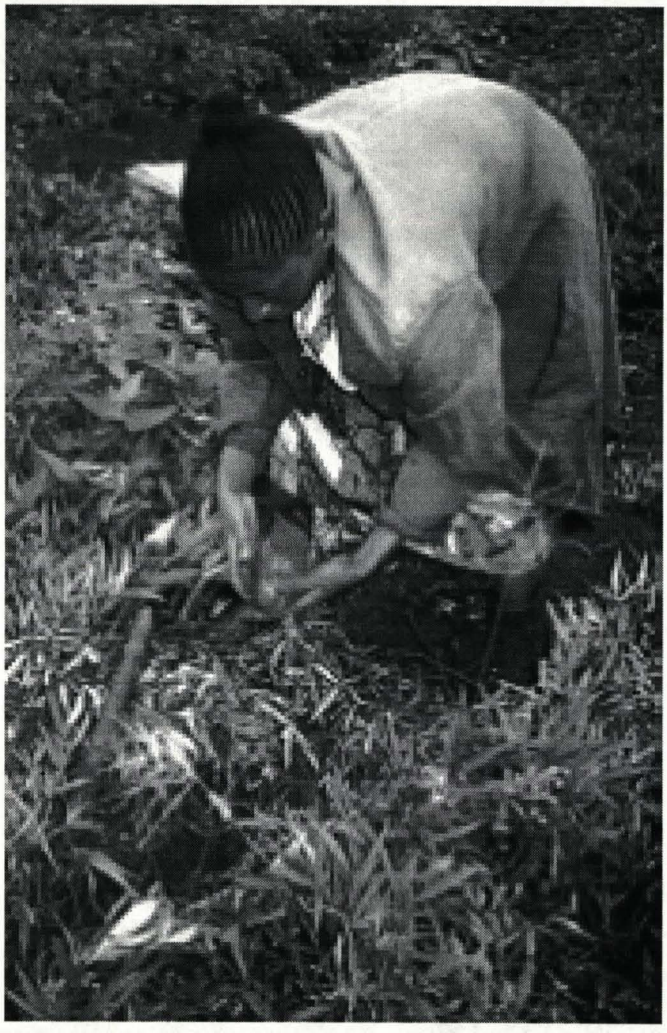


Plate 2.2 **Harvesting of sweet potatoes from wet soil using sticks instead of hoes (trial 7).**

2.4 Post-harvest storage trials

The conditions used for the storage experiments were designed to simulate the environment to which roots would be exposed during marketing. In the markets, roots are generally kept in opened storage sacks, in which they are exposed to ambient environmental conditions. The normal range of temperature and relative humidity in this case varies by season, but is generally within the range 18-30°C and 50-90% RH. Five experimental set-ups were used during the course of this study, as described below.

2.4.1 Storage set-up 1: Bins with humidification by airflow

Trial 1, 2 .

Location: NRI

The set-up is illustrated in Figure 2.2. Twelve plastic dustbins (B&Q) were placed in a temperature controlled room at 26°C. Within each of these, approximately 20 sweet potato roots (weighing about 5 kg) were placed on a platform. The platform was constructed from a plastic plant support and plastic covered chicken wire, and was supported at a height of about 30 cm.

In order to maintain high humidity a layer of water (approximately 70 mm) was placed in the bottom of each bin, and air was bubbled through this at a rate of approximately 3 litre $\cdot$ min^{-1} $\cdot$ bin^{-1}. A single pump (Charles Austin Pumps Ltd, UK) was used to provide an air-flow which was divided using a manifold to supply all 12 bins.

The humidity was measured at hourly intervals in six of the twelve bins using humidity probes (Vaisala, Helsinki, Finland), and recorded by data-loggers (Grant Instruments Ltd., Barrington, Cambridge) and was found to remain between 76 and 100%.

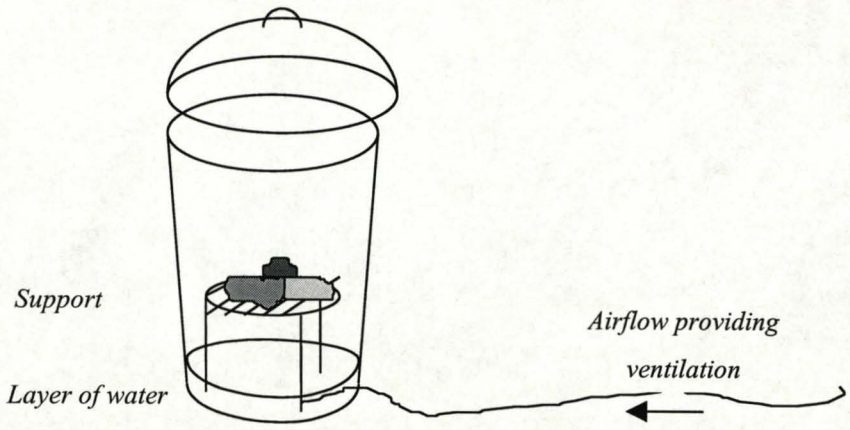


Figure 2.2 Schematic diagram of storage set-up 1: bins with humidification by airflow.

2.4.2 Storage set-up 2: bins with humidification by standing water

Trials: 5, 6

Location: NRI

Eight standard dustbins (B&Q) were equipped with hanging baskets of a diameter of 0.33 m (B&Q). About 30 sweet potatoes (~ 7.5 kg) were piled in the hanging basket (Plate 2.3c). The bins were placed in a CT room at 26°C. Possible build up of CO_2 was avoided by leaving a gap of 20 mm between the lid and the dustbin. All bins contained a layer of water at the bottom to provide the high humidity.

2.4.3 Storage set-up 3: Polythene woven storage bags

Trials: 3, 4

Location: ARTI, Ukiriguru, Tanzania

The storage conditions were adapted from traditional storage conditions as seen on the local markets in Mwanza. The roots were kept in woven polyethylene sacks, identical to those in which the roots are generally marketed. To simulate the higher humidity in the sacks during transport, the bags were closed during the first two days after harvest, then opened where the sides of the sacks were rolled down to half height. (Plate 2.3d and e). CO_2 and O_2 levels were checked once per day just before opening the sack, using a Combo Gas analyser (Bishop Instruments, UK). During assessment of wound healing the polyethylene bags were closed during the whole period of 4 days.

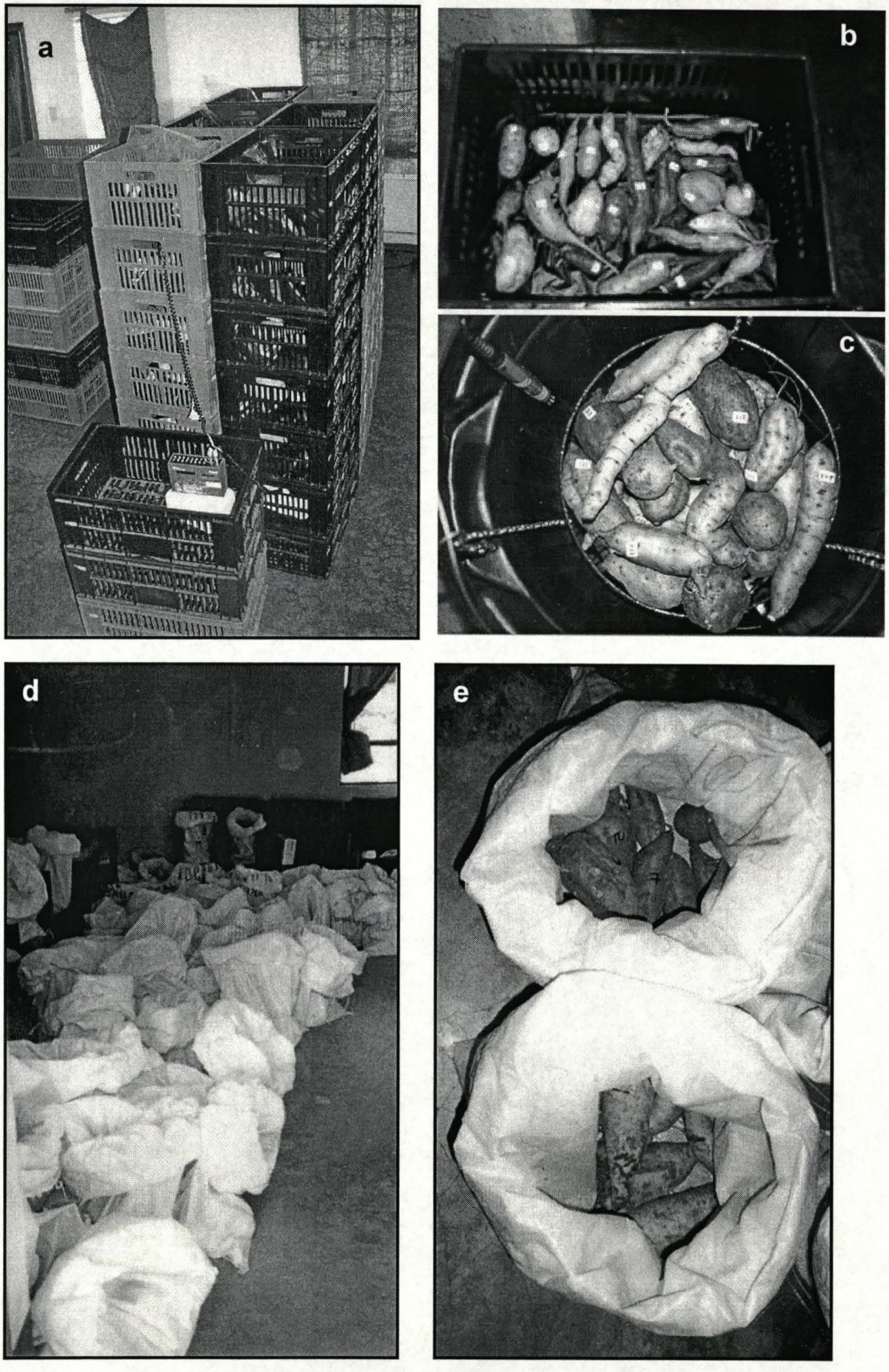


Plate 2.3 **Storage set-up. a) stack of crates; b) roots in crate lined with plastic; c) roots in hanging basket in dustbin; d) Storage at ARTI in polyethylene bags; e) roots in polyethylene bags**

2.4.4 Storage set-up 4: Plastic crates

Trials: 7, 8, 9, 10, 11, 12, 13

Location: NARL, Nairobi, Kenya

The store was set up with stacks of six crates (Plate 2.3d,e). Each crate contained up to 30 roots in such way that there was an equal number of roots for every cultivar. During the first two days the boxes were lined with plastic sheets or dustbin liners in order to simulate the high humidity in closed sacks to which the roots would be exposed when transported to the market. In six boxes the RH was measured every 30 minutes, using RH probes and recorded using data loggers. The measured conditions are presented in Appendix 1. The Temperature fluctuated between 18 and 27°C and RH fluctuated between 45 and 95%.

2.4.5 Storage set-up 5: Controlled relative humidity chambers

Trial: 14

Location: NRI

The roots were maintained at 3 different levels of humidity. Three separate chambers were used (Figure 2.3). In one chamber a high RH was maintained by means of an air flow of 3.5 $l \cdot hr^{-1}$ through a layer of water in the base of the chamber. Humidification of the air was improved by using fish-tank stones for dispersal. The RH achieved was 97%.

For the two other chambers an intermediate humidity was maintained using two supplies of air, one of low humidity (sourced from outside the CT-room) and one of high humidity (obtained by bubbling through water). The supply of these two sources of air was controlled using an adjustable humidity sensor[1] placed within the chamber. Although the aim was to maintain one chamber at 50% and one at 75%, in practice the humidities attained were in the range of 56.6 - 62.3 and 64.5 - 70.5% with an average of 58% and 65% respectively. The conditions recorded during the trials are presented in Appendix 1.

[1] The humidity controllers were kindly lend to us by Dr Ian Gubb, Wye College, UK

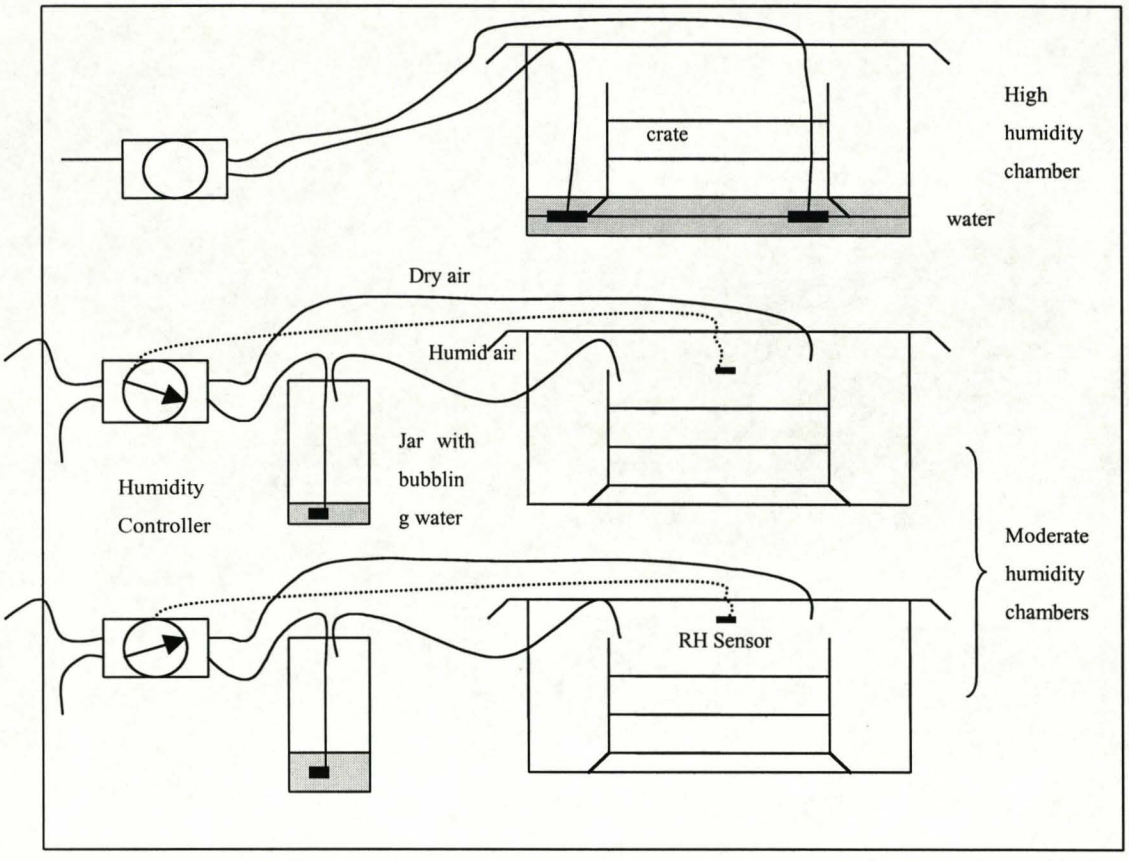


Figure 2.3 Schematic diagram of storage set-up 5: Controlled humidity chambers.

Table 2.2 Overview of the cultivars used in each of the trials

Trial	Cultivars				
Trial 1	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 2	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 3	440025	Bagala	Itemve	Polista	Mwanamonde
	440037	Bilagala	Kagole	Shinamugi	Sinia B
	440088	Budagala	Kombegi	SP/93/34	SPN/0
	440113	Budagala mpya	Luganza	Tabu Waseka	SP/93/2
	440121		Lutambi	TIS 8250	SP/93/23
	440215	Iboja Ipembe	Nyamwisekeleya	Tula Omushako	
Trial 4	Mwanamonde	Sinia B	SPN/0	SP/93/2	SP/93/23
Trial 5	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 6	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 7	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 8	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 9	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 10	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 11	BP1-SP-2	Julian*	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 11B	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada	Zapallo
Trial 12B	Santa Amaro,	SPK 013,	Sowola,	KSP 20,	
	Mugande	NIS/94/320	Naveto,	Yan Shu 1	
Trial 13	BP1-SP-2	Julian	KSP 20	SPK 004	Yan Shu 1
	Caplina	Kemb 10	Salyboro	Yarada**	Zapallo
Trial 14	BP1-SP-2	Julian	KSP 20	Yarada	Polista
	Caplina	Kemb 10	Salyboro	Yan Shu 1	SPN/0
			SPK 004	Zapallo	SP/93/2

* *not in trial 11b*

** *not in trial 13b*

Table 2.3 Overview of location, field design and planting and harvesting dates for each of the trials.

	Location	Number of cultivars	Field design	Date of planting	Date of harvesting
Trial 1	CIP	5	-	15-7-96	22-1-97
Trial 2	CIP	5	-	15-7-96	17-3-97
Trial 3	ARTI (Station)	22 9	CRD*, 3 rep 2 rows x 6 m CRD*, 2 rep 6 rows x 6 m	28-12-96**) 28-12-96**)	23-6-97 23-6-97
Trial 4	On Farm Trial	5	2 rows, 2 farms	Jan 97	7-7-97
Trial 5	CIP	5	-	July 97	27-11- 97
Trial 6	CIP	5	-	July 97	Jan 98
Trial 7	CIP	10	3-4 rows 100 plants per row	20-11-97	28-4-98
Trial 8	CIP	5	3-4 rows 100 plants per row	20-11-97	12-5-98
Trial 9	CIP	10	CRD*, 3 reps 90/120 plants per cult	25-5-98	27-10-98
Trial 10	CIP	10	CRD*	25-5-98	4-11-98
Trial 11	CIP	10	CRD*, 3 reps 90/120 plants per cult	June 98	11-11-98
Trial 11B **Trial 12B**	CIP	8	-	July 98	1-12-98
Trial 13	CIP	9	-	July 98	21-12-98
Trial 13B	CIP	10	-	July 98	7-1-99
Trial 14	CIP ARTI (Lake Site)	10 3	-	Nov 98 Nov 98	March 99 March 99

**) CRD = Complete Randomised Design*

***) replanted on the 17th of January due to poor establishment of some vines.*

Table 2.4 Overview of storage set-up and conditions for each of the trials

	Storage	Location	Temperature	RH	
Trial 1	Bins with humidification by airflow	NRI	26.1 ± 0.5°C	82.2 ± 4 %	
Trial 2	Bins with humidification by airflow	NRI	26.1± 0.1°C	73.2±-7.3%	
Trial 3	Polythene woven storage bags	ARTI Ukiriguru	24.2 ± 0.6°C	84.1 ± 7.6%	Ambient: T= 24.2 ± 1.4°C, RH= 56.1 ± 5.7% Wound healing: T = 24.5 ± 6.0, RH = 97.2 ± 6.0%
Trial 4	Polythene woven storage bags	ARTI Ukiriguru	23.5 ± 0.9°C	64.5 ± 8.8%	Ambient: T=23.1 ± 0.9°C, RH= 49.1± 11.9%
Trial 5*	Bins with humidification by standing water	NRI	≅26°C	≅ 95%	
Trial 6*	Bins with humidification by standing water	NRI	≅26°C	≅ 95%	
Trial 7	Plastic crates (lined with plastic for 2 days)	NARL – Nairobi, Kenya	20.7 ± 1.4°C	85.9 ± 6.5%,	
Trial 8	Plastic crates (lined with plastic for 2 days)	NARL – Nairobi, Kenya	20.7 ± 1.6°C	83.3 ± 6.5%,	
Trial 9	Plastic crates (lined with plastic for 2 days)	NARL – Nairobi, Kenya	21.1 ± 1.7°C	68.6 ± 10.5%	
Trial 10	Plastic crates (lined with plastic for 2 days)	NARL – Nairobi, Kenya	21.0 ± 1.9°C	67.6 ± 12%	
Trial 11 Trial 11B	Plastic crates (lined with plastic for 2 days)	NARL – Nairobi, Kenya	20.7 ± 1.9°C	72.3 ± 11.2%	
Trial 12B	Plastic Crates	NARL – Nairobi, Kenya	21°C	67.3%	
Trial 13	Plastic Crates	NARL – Nairobi, Kenya	26°C	85-90%	
Trial 14	Controlled relative humidity chambers	CT-room, NRI	T = 26°C,	Low 58% Intermediate 65% High 95%	

- *Data estimated from regular readings*

Chapter 3

Sweet potato storability and weight loss

3.1 Introduction

This chapter describes an investigation to determine the role of weight loss in storability. Weight loss is often used to measure losses in post-harvest studies of perishable commodities, not only because of the actual economic loss due to reduction in saleable weight, but also because it can reflect quality changes of the product. Since a sweet potato storage root is living tissue, it loses weight continuously due to respiration and transpiration. These changes may adversely affect the quality of the root depending on the duration of storage.

The objectives of this chapter were to investigate the range in weight loss among sweet potato cultivars as a function of time when kept under tropical marketing conditions. Eleven storage trials were carried out in total, some of which were conducted in the UK under simulated tropical conditions, others in Kenya and Tanzania under local conditions. The rate of respiration was measured to determine its contribution to total weight loss. Furthermore, weight losses were related to rotting, sprouting and marketability of the roots.

3.2 Literature review

Under tropical conditions the shelf life of sweet potatoes is short. Under tropical conditions the high temperatures affect the shelf life by increasing the rate of weight loss, both by water loss (transpiration) and respiration rate (carbohydrate metabolism). In the Lake Zone in Tanzania the shelf-life was found to be as short as 6 to 8 days (Thomson *et al.*, 1997).

There is evidence that the short-shelf-life is associated with accelerated weight loss (Rees *et al.*, 1998). Pit-storage trials in Bangladesh resulted in 20% weight loss after 5 weeks of storage (Jenkins, 1982). In Malawi the losses were 40% after 1 month in mound-storage trials (Mbeza, 1997) and in Papua New Guinea sweet potatoes could be stored in mounds for up to 3 months, but the weight losses often exceeded 40% (Woolfe, 1992).

3.2.1 Curing

In the United States sweet potatoes are normally cured for ca 10 days (T=32°C, RH = 90%) before they are stored under controlled conditions (13-15°C, RH = 95%). In this situation sweet potatoes can be kept easily for 6 to 12 months. The weight losses during curing can be around 2.7 to 4.3% while total losses during subsequent storage are 4.3 to 11.3% after 50 weeks (Picha, 1986).

Under tropical conditions sweet potatoes may cure naturally (Collins and Walter, 1985). Jenkins (1982) reported that artificial curing of sweet potatoes before storage did not result in any additional beneficial effects. However, Gull and Duarte (1974) reported reduced weight loss when sweet potatoes were artificially cured before storage, and while weight losses of uncured roots were 18.2% after 90 days, cured roots had lost 9.3 and 11.6%.

3.2.2 Respiration rate

For most fresh products the rate of respiration is considered as an important factor affecting storability. Commodities with a low respiration rate generally have a longer storage life (Wills *et al*, 1998). When the temperature rises the respiration rate also increases. For potatoes a rise of temperature from 5 to 20°C resulted in a three fold increase in respiration (Rastkovski, 1987).

3.2.3 Cultivar

There is evidence that the shelf-life is affected by the choice of cultivar. A study in Sierra Leone revealed that weight losses among sweet potato cultivars varied from 27 to 40% during 20 days of storage (George and Kamara, 1988). Research in the Philippines revealed that the storability could vary from 1 to 3 months depending on the cultivar (Acedo *et al*, 1996).

3.3 Materials and Methods

The experiments in this chapter were carried out upon the sweet potato roots obtained from trial 1 to 11. For details on cultivar, field information and storage conditions refer to Chapter 2.

3.3.1 Measurements of weight loss

Weight losses were determined by taking the weights of the individual roots. Care was taken that no extra damage occurred during the weighing process. In most trials all roots were measured, except in trial 3 where six roots were randomly selected to represent each replicate. The time intervals at which roots are weighed are presented in Table 3.1. Roots that had started to rot were removed and sprouting was recorded at first occurrence.

Table 3.1 Summary of storage trials used for weight loss experiments

Trial	Number of cultivars	Roots per cultivar	Number of Blocks	Time intervals for weight loss recording (days)
1	5	6 – 30	CRD	11, 31
2	5	14 –31	CRD	13, 26, 40, 55
3	29	18	3	7, 14, 21
5	5	24	6	2, 6, 13, 21, 27, 34, 49, 64
6	5	24	6	3, 6, 13, 26
7	10	36	6	1, 2, 3, 4, 5, 6, 7, 9, 12, 16, 20, 27
8	5	10	CRD	3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
9	10 + 2 potato cultivars	10	CRD	2, 3, 4, 6, 8, 10, 12, 14, 16
10	10	24	6	8, 27, 41
11	10 + 2 potato cultivars	10	CRD	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19

CRD : Completely Randomised Design

- In storage trial 1 and 2 the roots were divided as a randomised complete block design. The number of roots per cultivar varied from 6 to 31 (Table 3.2). The data were analysed by ANOVA using 10 and 14 randomly selected roots for each cultivar respectively (Thus for trial 1 the analysis had to take 5 missing data points into consideration)

Table 3.2 Number of roots per cultivar for weight loss measurements in trial 1 and 2.

	Yan Shu	Kemb 10	KSP20	Zapallo	SPK004
Trial 1	30	6	17	10	9
Trial 2	18	14	20	15	31

- The roots for trial 3 were grown as two replicates, as randomised complete block design. Storage-rep1 consisted of roots from field-rep 1, and storage-rep 2 from field-rep 2. Storage-rep 3 was a mixture of field-rep1 and 2. Each storage replicate consisted of approximately 25 roots per cultivar. The three storage reps were kept in separate corners of the storage room. Weight loss measurements were conducted upon 6 roots per replicate. The data were analysed per storage time using ANOVA, with replicate as a blocking factor.
- In trial 4, four roots per cultivar were divided between four storage sacks, so that every bag contained one storage root of each cultivar. In the analysis, storage sack was used as a blocking factor.
- In trial 5 and 6, sweet potato roots were randomly divided between the storage-bins giving 3 to 5 roots per cultivar per bin. The data were analysed by ANOVA as a split plot design, using 'bin' as the whole plot-blocking factor.
- In trial 7, 36 roots per cultivar were randomly divided between 36 crates, so that every crate contained one root of each cultivar. The data were analysed by ANOVA as a split plot design, using stacking level of the crate as the blocking factor (6 heights and 6 roots per block).
- In trial 10, the 24 roots were divided between 24 crates (similar to trial 7) and height was used as blocking factor (6 heights and 4 roots per height). In trial 8, 9 and 11 the roots were randomly divided between 6 crates, each crate containing one root per cultivar. The data were analysed by ANOVA as split-plot design, using crate as a blocking factor.

3.3.2 Respiration

Respiration rates were measured for roots within storage trial 3. These came from two field trials, termed the UYT and GET (see Chapter 2, section 3). Six roots per cultivar were measured from UYT, and three roots from GET. Measurements were taken between 5 and 7 days after harvest and at 16 days after harvest. Each root was weighed, and placed into a 3.2 litre sealed glass jar (Plate 3.1). After one hour the percentage CO_2 in the headspace of the glass jars was measured with a Combo Gas Analyser (David Bishop Instruments Ltd, Heathfield, UK).

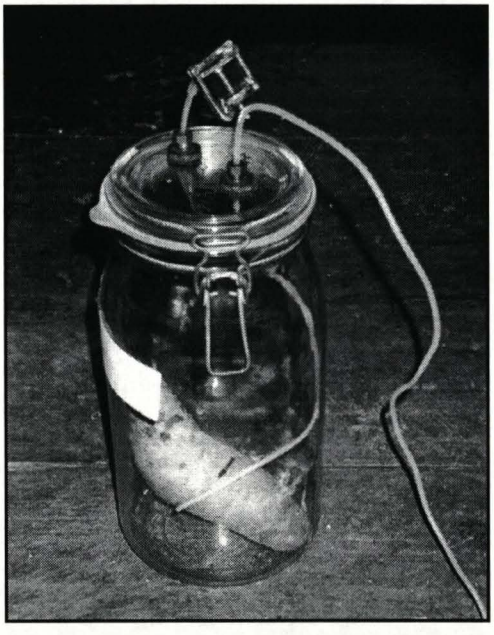


Plate 3.1 **Sealed glass jar with a sweet potato root during measurements of respiration rate.**

The respiration rate was calculated using the following equation:

$$R = C_{CO2} * (V_{jar} - m_{sp}) / (m_{sp} * t) \qquad (cm^3 \cdot kg^{-1} \cdot hr^{-1})$$

Where:

R = respiration rate ($ml \cdot kg^{-1} \cdot hr^{-1}$)

m_{sp} = weight of the sweet potato (kg) or (litre*)

C_{CO2} = concentration of CO_2 in the headspace (%)**

V_{jar} = volume of the jar, 3.2 litre

t = time in the glass jar (hr)

* m_{sp} was used to approximate the volume of the sweet potato assuming a density of 1 $g \cdot ml^{-1}$.

** The combo was calibrated to read 0% CO_2 for air, so no correction was necessary for initial CO_2 concentration.

Weight loss due to respiration was derived using the respiration rate and the following equation for product respiration assuming that carbohydrates were the main respiratory substrate:

$$\boldsymbol{C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + energy}$$

One mole of gas has a volume of 24.2 litre at 22°C, and one mole $C_6H_{12}O_6$ weighs 180 g,

Thus:

1 ml of CO_2 = 1/24200 mole CO_2 = $4.13 * 10^{-5}$ mole CO_2

1 mole $C_6H_{12}O_6$ metabolised gives 6 moles of CO_2 g

For 1ml CO_2 produced, $6.89 * 10^{-6}$ mole $C_6H_{12}O_6$ was metabolised,

This is equivalent to $1.24 * 10^{-3}$ g $C_6H_{12}O_6$

$$\boldsymbol{1\ ml\ CO2\ /hr = 1.24 * 10^{-3}\ g\ C_6H_{12}O_6\ metabolised\ /hr}$$

3.3.3 Rotting

In trial 3 sweet potato roots were assessed for rotting. This was the only trial where rotting roots were not removed. The extent of rotting for each replicate was assessed at the start of the trial and at weekly intervals by visual scoring of all roots. The scores related to percentage rotting (Table 3.3).

Table 3.3 Scores for external rotting

Score	Percentage of surface showing visible rotting
1	0%
2	1-10%
3	11-25%
4	26-50%
5	51-75%
6	76-100%

3.3.4 Marketability

The roots remaining after the storage trial 10 (Nairobi) were assessed for their saleability in terms of appearance. All the roots of 10 cultivars were categorised by a Kenyan housewife into three categories (Table 3.4). The roots were 8 weeks old.

Table 3.4 Categories of appearance with their selection criteria

Category 1	Category 2	Category 3
Roots that would be bought at normal price	Roots that would be bought at low price	Roots that would never be bought

3.3.5 Data analysis

All analyses were carried out using GENSTAT (Release 3.2 (PC/Windows 95) Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Corrections for inconstant variance due to repeated measurements were made using the Greenhouse & Geisser epsilon by adjusting the degrees of freedom. Other relationships between weight loss and respiration rate, rotting and saleability were analysed using linear regression.

3.4 Results and Discussion

3.4.1. Weight loss of cultivars grown in Tanzania

The mean weight losses for 29 East African sweet potato cultivars after 1, 2 and 3 weeks are presented in Table 3.5 in order of increasing weight loss after 21 days. There was a wide range in weight loss with significant differences between cultivars ($P < 0.001$). The overall mean was 10.4% after 1 week, 21.2% after 2 weeks and 31.3% after 3 weeks. Poor storing cultivars included Budagala mpya, Mwanamonde, Budagala and Iboja which lost more than 40% of their weight within 3 weeks, while relatively good storing cultivars included Bilagala, Kagole and 440088 which lost 12.6, 16.5 and 17.9% respectively in the first three weeks. The weight losses were approximately linear with storage time. It was observed that the weight losses for the UYT trial were generally higher than for the GET trial. This indicates that field conditions and handling are probably important factors for shelf-life. The difference was extreme for the cultivar SPN/0 which occurred in both field trials, the GET roots having lost 23.6% while the UYT roots lost 36.0% of weight in 3 weeks.

After three weeks the quality of the roots was so poor that trials were ended. This confirmed the findings of Thomson *et al.,* (1997) who reported that the shelf life of sweet potatoes in the Lake Zone of Tanzania is extremely short.

Further studies have ascertained that the differences among cultivars were highly consistent over two seasons (Rees *et al., 1998*).

Table 3.5 Weight losses (as % initial weight) and respiration rates of 29 cultivars grown at ARTI Ukiriguru Tanzania after storage under simulated market conditions. Roots are from 2 field trials GET and UYT. The weight losses are the means of 3 replicates, each of which consists of 6 roots. The respiration rates are the means of 3 roots for GET and 6 roots for UYT.

Cultivar	Field Trial		Weight loss (% fresh weight)			Respiration rate (ml/kg/hr)		
	GET	UYT	7 days	14 days	21 days	after 5-7 days		
Bilagala	GET		4.5	8.4	12.6	33.1		
Kagole	GET		6.0	11.3	16.5	28.4		
440088	GET		6.9	12.5	17.9	44.2		
440121	GET		6.9	13.9	22.0	38.1		
440025	GET		7.7	15.1	22.4	45.6		
Luganza	GET		9.0	17.2	22.6	55.5		
Ipembe	GET		9.7	16.6	23.3	39.7		
SPN/0	GET		7.8	16.1	23.6	35.7		
Tula Waseka	GET		8.5	16.3	24.2	42.5		
Nyamwisekeleya	GET		9.6	17.5	25.1	50.5		
TIS 8250	GET		9.0	17.4	25.2	51.8		
440037	GET		8.9	19.7	25.5	49.5		
SP/93/23		UYT	9.1	18.4	25.9	25.5		
Kombegi	GET		9.4	18.9	27.9	55.1		
Itemve	GET		8.7	19.0	28.8	58.7		
Tula Omushako	GET		8.5	18.4	28.9	60		
SP/93/34		UYT	11.0	20.7	29.5	39.2		
Polista	GET		8.4	18.9	29.7	42.6		
Sinia B		UYT	10.3	20.3	31.2	36.9		
Shinamugi	GET		10.9	23.6	31.3	117.6		
SP/93/2		UYT	9.3	20.4	32.5	43.3		
440113	GET		10.4	20.5	32.9	81.1		
Lutambi	GET		10.2	21.9	33.7	82.1		
440215	GET		11.8	24.9	36.0	64.6		
SPN/0 (UYT)*		UYT	10.7	21.9	36.0	40.7		
Bagala	GET		12.4	25.4	37.8	139.5		
Budagala mpya		UYT	13.9	27.5	41.8	57.1		
Mwanamonde	GET		12.9	30.6	43.9	52.8		
Mwanamonde (UYT)*		UYT	12.6	29.0	44.5	50.5		
Budagala		UYT	14.1	29.1	45.6	101.0		
Iboja		UYT	17.6	33.9	46.2	85.6		
Mean			**10.4**	**21.2**	**31.3**	**55.7**		
Cultivar effects:						GET	GET-UYT	GET
P- value			< 0.001	< 0.001	< 0.001		< 0.001	
S.e.m.			1.03	1.78	2.95	12.5		8.86
S.e.d.			1.46	2.51	4.17	17.7	15.3	12.5
LSD			2.92	5.26	8.34	35.2	30.5	24.9

SAFE, Cranfield University, Quirien van Oirschot, 2000

3.4.2 Respiration Rate

The respiration rate, measured at 5 to 7 days after harvest varied from 16.9 to 195.2 ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$ per root, with a mean of 55.7 ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$. There were significant differences among the cultivars; Bagala, Budagala, Shinamugi, 440113, Iboja and Lutambi had significant higher respiration rates (81-140 ml $\cdot kg^{-1} \cdot hr^{-1}$) than Kagole, 440121, Bilagala, SPN/0, SP/93/34, SP/93/23 and Sinia B (26-39 ml$\cdot kg^{-1} \cdot hr^{-1}$). There was a significant correlation between respiration rates at 5-7 and weight loss after 7 days (Figure 3.1).

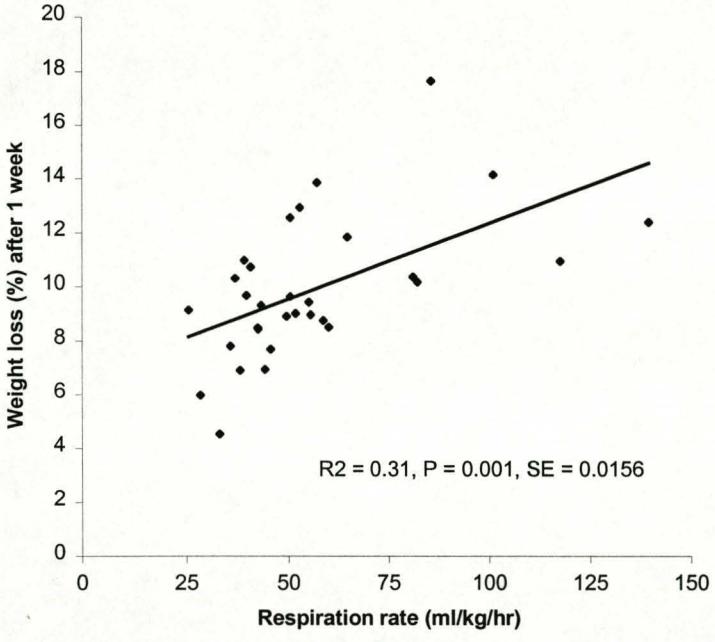


Figure 3.1 The relationship between respiration rate and fresh weight loss after 1 week storage for 29 cultivars (T = 24.2 ± 1.4 °C, RH = 84.1 ± 7.6%).

At 16 days after harvest the respiration rates were measured again for the roots of nine of the cultivars (grown in the UYT). The respiration rates varied from 46.4 to 173.5 ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$ (Figure 3.2), but in all cases the rates were higher than at 5 to 7 days after harvest. This is in contrast to findings from other scientists like Picha (1986) who observed a decline in respiration rate after the day of harvest from 23-27 ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$ to 3 to 10 ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$ during storage. Frydecka-Mazurczyk (1978) also reported a decrease in respiration for potatoes during the first week after harvest.

In this respect the behaviour of the Tanzanian crop is different from both the literature and the Kenyan crop, as will be shown later.

The increase in respiration rate indicates an increase in metabolic activity. This is due to increased stress caused by high water loss which is clearly a result of the storage conditions. Schippers (1977) also found that increased respiration rates were a sign of physiological disorder in potatoes which coincided with discoloration of the tissue. Interestingly the correlation with weight loss and respiration, which was found at 7 days, is not maintained.

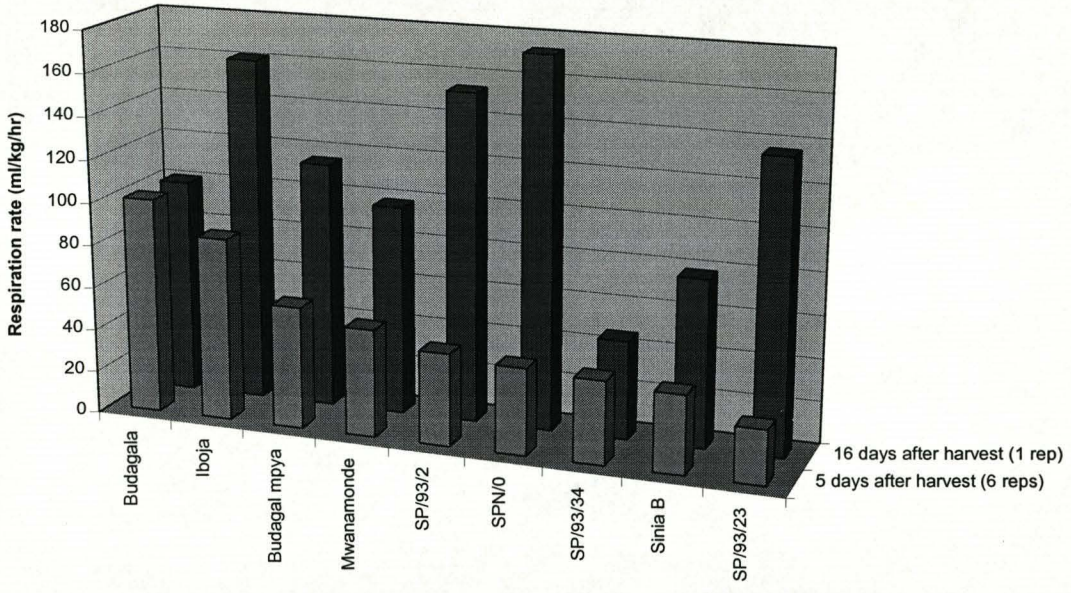


Figure 3.2 Respiration rates of 9 cultivars (UYT trial) at 7 and 16 days after harvest (T = 24.2 ± 1.4 °C, RH = 84.1 ± 7.6%).

The weight loss due to respiration represented however a relatively small amount of the total weight loss (Figure 3.3). In most cases the weight losses by respiration was between 5 and 15% of total weight loss. The only exception was the cultivar Shinamugi for which 22% of weight loss was estimated to be due to respiration. Some scientists have reported similar percentages, for example Ashiv-Mehta *et al.,* (1997) found that 3.6 to 6.1% of weight loss in potatoes was due to respiration, however others reported that weight loss due to respiration ranges from 18.5 to 100% depending on the temperature and relative humidity (Butchbaker *et al.*, 1973). It was concluded that for improving sweet potato

storability under tropical conditions the emphasis should be on controlling transpiration and evaporation.

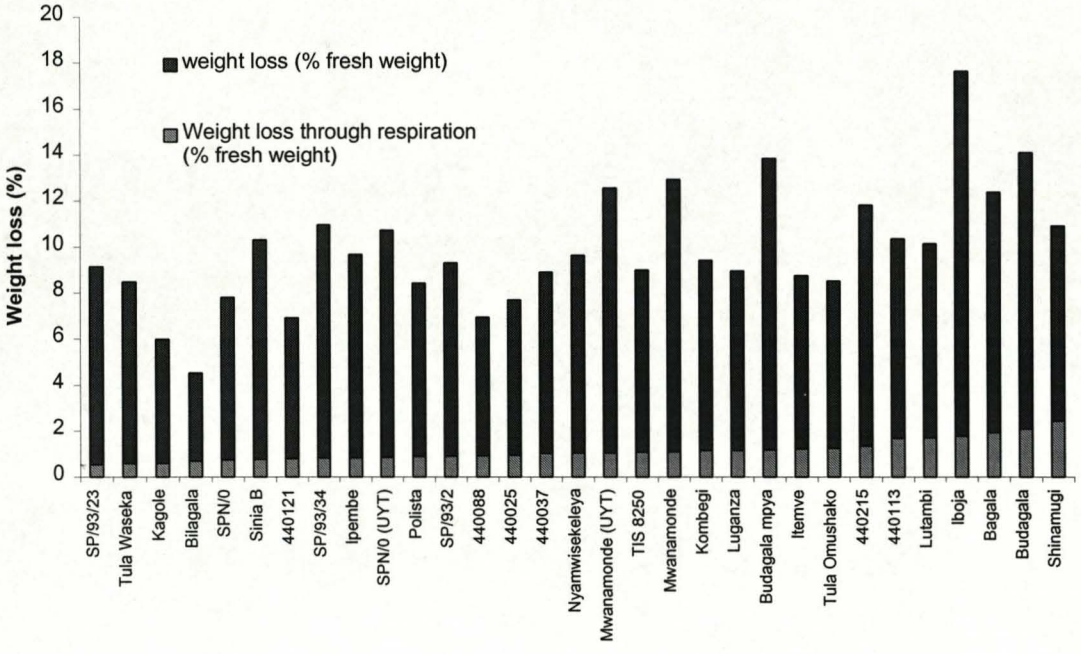
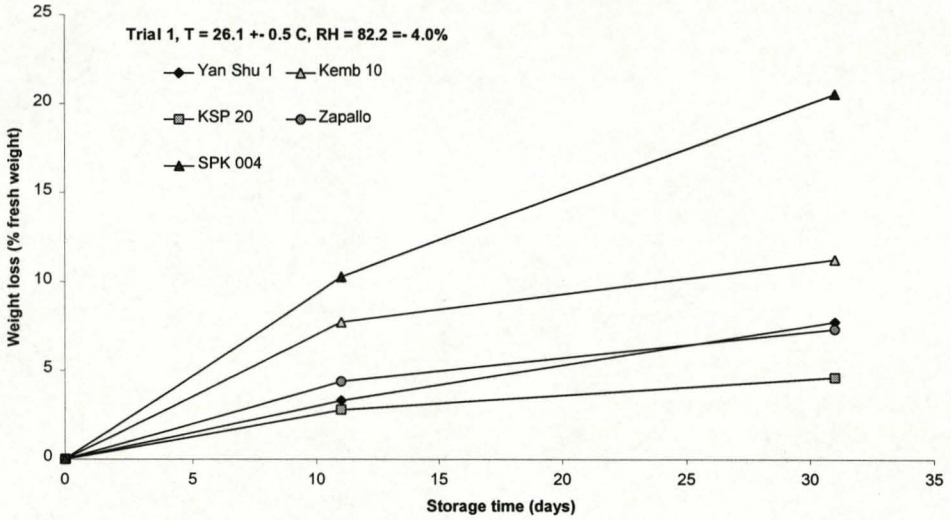
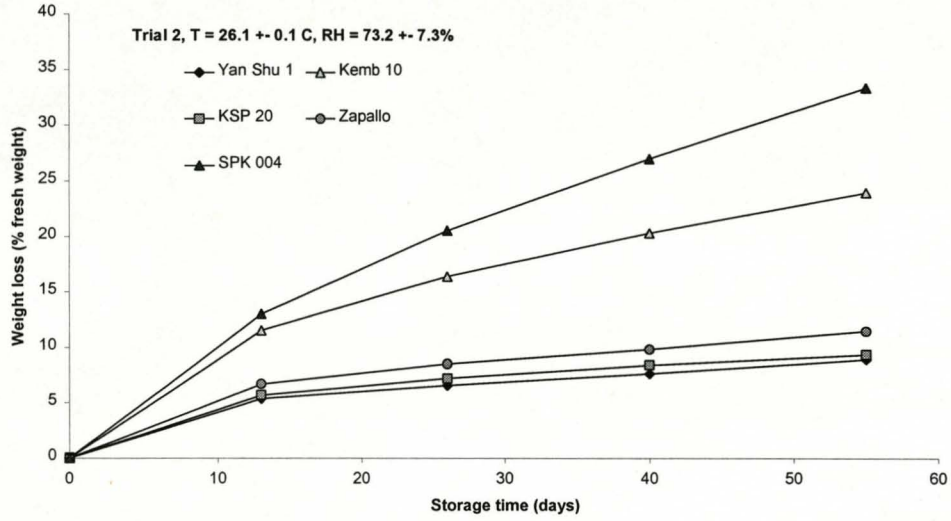


Figure 3.3. Total weight losses and weight loss through respiration rate of sweet potato cultivars after 7 days. Total weight loss was the mean of 3 replicates each containing 6 roots. Weight loss by respiration was determined using the mean rate of 3 measurements per cultivar. It was assumed that the rate of respiration was constant over 7 days (T = 24.2 ± 1.4 °C, RH = 84.1 ± 7.6%).

3.4.3 Weight losses of cultivars grown in Kenya

Nine weight loss trials were carried out upon sweet potato cultivars grown in Kenya under tropical storage conditions. Figures 3.4a–i present the cumulative weight loss curves of each trial. All trials included the cultivars Yan Shu 1, Kemb10, KSP 20, Zapallo, SPK 004 and for trials 7, 9, 10 and 11 five additional sweet potato cultivars were included , BP1-SP-2, Caplina, Salyboro, Yarada, Julian. Trial 9 and 11 also included two potato cultivars: Kihoro and Nyaya. The results of statistical analyses are summarised in Table 3.6a-c. For simplicity, cultivar means are shown only for selected storage times, but the analyses consider whole data sets.





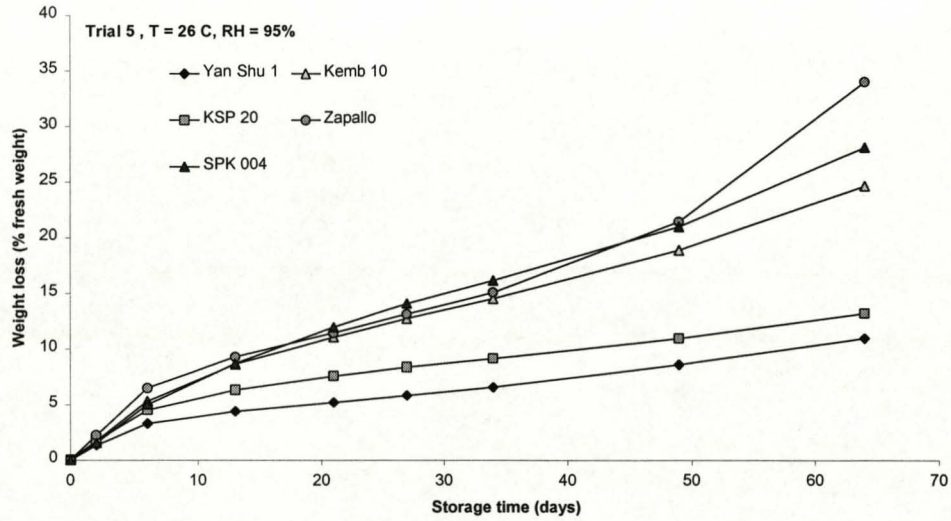
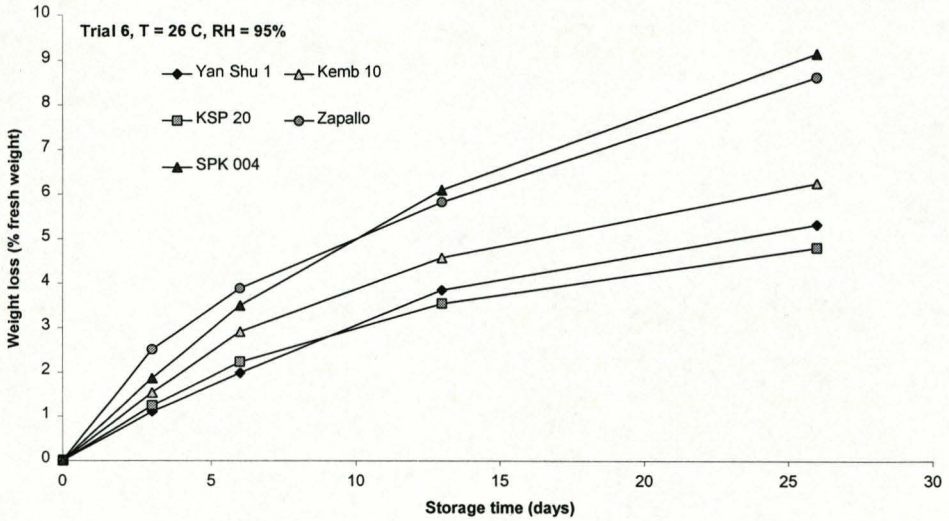
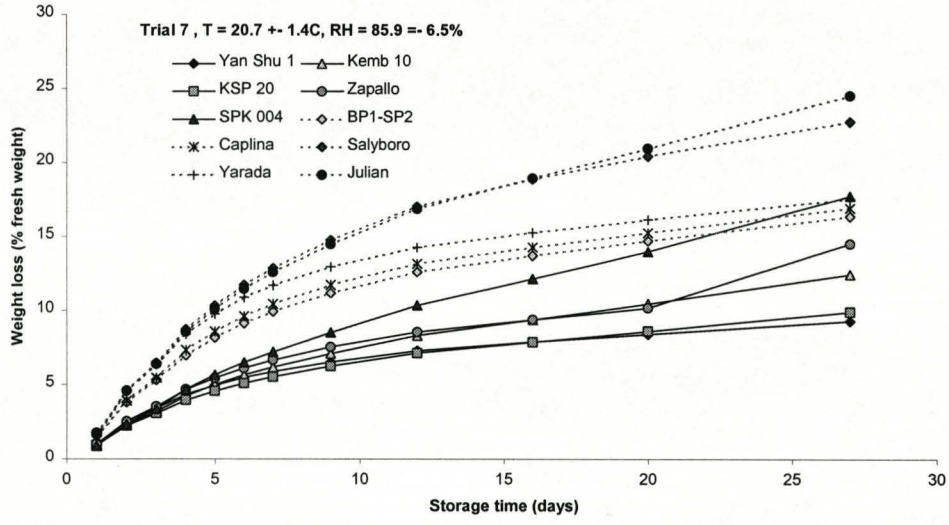


Figure 3.4.a-c Cumulative weight loss [%] of 5 sweet potato cultivars stored under simulated tropical conditions at NRI.





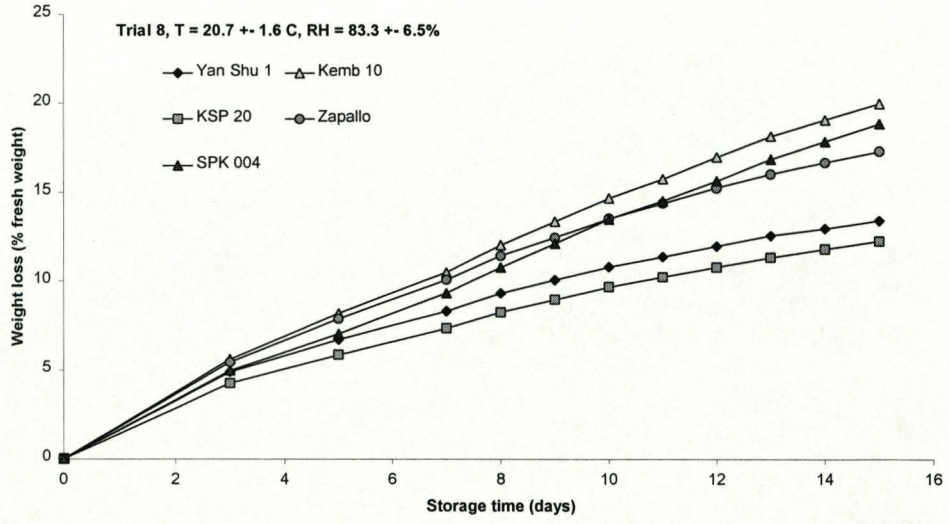


Figure 3.4.d-f Cumulative weight loss [%] of 5 or 10 (4.4.e) sweet potato cultivars grown in Kenya. Trial 6 was stored under simulated tropical conditions at NRI, UK. Trials 7 and 8 were stored under ambient conditions at NARL, KARI, Nairobi, Kenya.

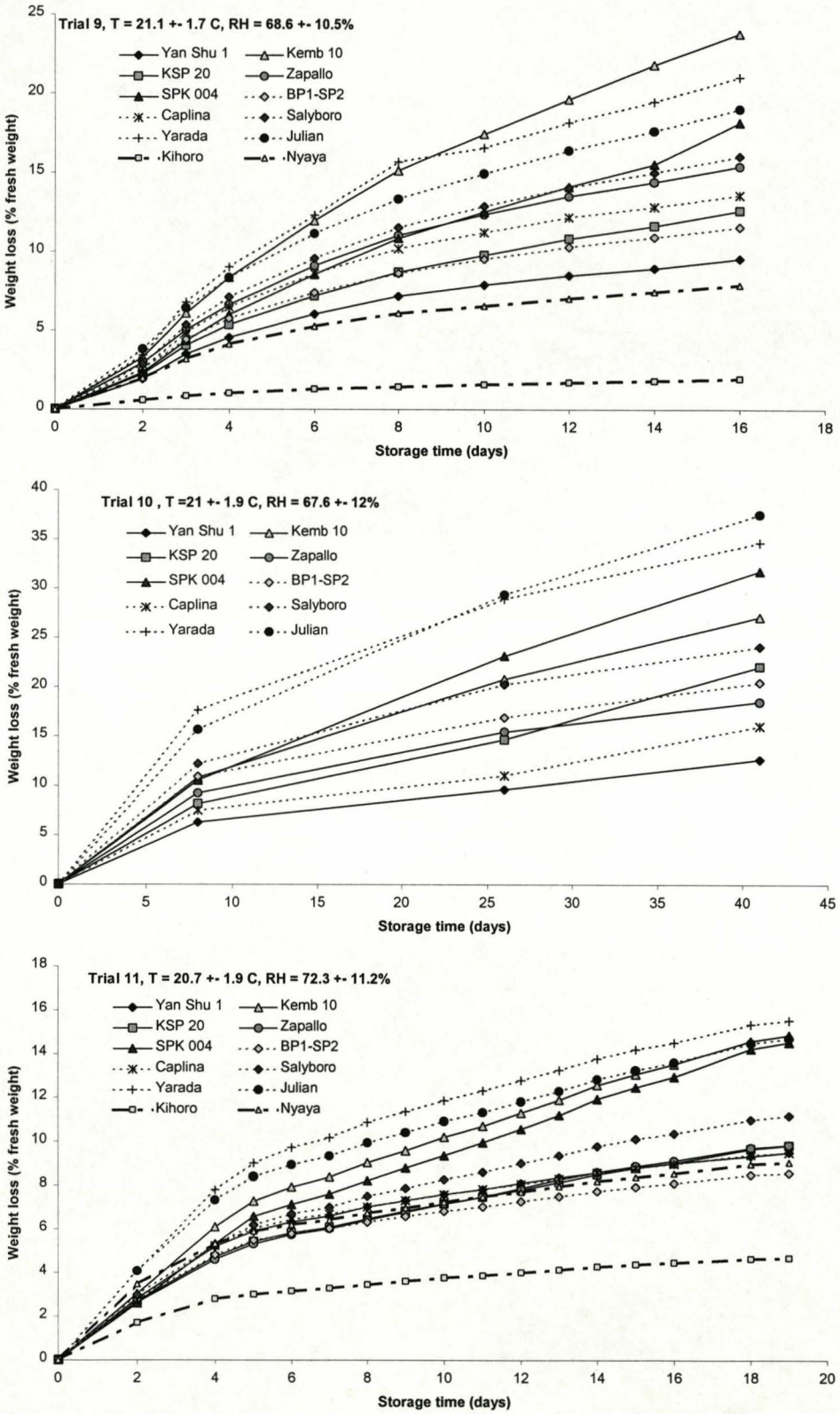


Figure 3.4.g-i Cumulative weight loss [%] of 10 sweet potato cultivars and 2 potato cultivars (3.4 g and i) grown in Kenya, and stored under ambient conditions at NARL, KARI, Nairobi, Kenya.

Table 3.6 a Weight loss during storage for 5 sweet potato cultivars grown in Kenya. The significance levels of cultivar, storage time and their interactions in trial 1, 2, 5 and 6.

Trial 1 NRI January 1997

* Note that in Trial 1 the ANOVA did not include storage time as a factor. Data were analysed separately for each storage time

Cultivar	11 days	31 days
Yanshu	2.92	9.08
Kemb10	7.83	12.35
KSP20	2.53	4.03
Pumpkin	4.36	7.32
SPK004	10.18	20.43

Cultivar	P < 0.001	P < 0.001
Sed cult	= 0.865	= 2.429
LSD	= 1.763	= 4.954

Trial 2 NRI March 1997

Cultivar	13	26	55	Mean
Yanshu	5.15	6.23	8.58	6.81
Kemb10	11.51	16.36	23.96	18.03
KSP20	5.46	7.06	9.13	7.46
Pumpkin	6.50	8.29	11.16	8.88
SPK004	13.08	20.26	31.51	22.71

Cultivar	P < 0.001	Storage time	P < 0.001
Sed cult	= 1.64		
Sed stor	= 1.47	Interactions	
Sed cult*stor	= 3.28	Cult*Stor	P = 0.201

Trial 5 NRI Dec 1997

Cultivar	6	13	27	64	Mean
Yanshu	3.28	4.37	5.81	10.96	5.75
Kemb10	4.77	7.68	11.32	22.99	11.03
KSP20	4.32	6.04	7.95	12.60	7.37
Pumpkin	5.16	8.01	11.78	29.71	12.32
SPK004	4.61	8.01	13.10	26.66	12.44

Cultivar	P = 0.017	Storage time	P < 0.001
Sed cult	= 2.15		
Sed stor	= 0.638	Interactions	
Sed cult*stor	= 2.53	Cult*Stor	P < 0.001

Trial 6 NRI Jan 1998

Cultivar	6	13	26	Mean
Yanshu	2.14	3.93	5.41	3.16
Kemb10	2.88	4.53	6.23	3.79
KSP20	2.28	3.65	4.92	3.03
Pumpkin	3.98	5.90	8.63	5.27
SPK004	3.66	6.32	9.45	5.33

Cultivar	P < 0.001	Storage time	P < 0.001
Sed cult	= 0.600		
Sed stor	= 0.223	Interactions	
Sed cult*stor	= 0.738	Cult*Stor	P = 0.014

Table 3.6 b Weight loss during storage for 5 and 10 sweet potato cultivars grown in Kenya. The significance levels of cultivar, storage time and their interactions in trial 7, 8, 9 and 10. Trial 9 also included two potato cultivars.

Trial 7 Nairobi April 1998

Cultivar	6	12	27	Mean
Yanshu	5.41	7.20	9.17	5.51
Kemb10	5.72	8.43	12.65	6.35
KSP20	5.03	7.02	9.72	5.35
Pumpkin	6.24	8.77	14.55	6.81
SPK004	6.58	10.49	18.04	7.90

Cultivar	P = 0.011	Storage time	P < 0.001
Sed cult	= 0.708		
Sed stor	= 0.337	Interactions	
Sed cult*stor	= 1.01	Cult*Stor	P = 0.001

Trial 8 Nairobi May 1998

Cultivar	5	9	13	Mean
Yanshu	6.72	10.08	12.59	10.23
Kemb10	8.19	13.37	18.16	14.03
KSP20	5.85	8.96	11.36	9.17
Pumpkin	7.88	12.46	15.89	12.71
SPK004	7.03	12.13	16.87	12.86

Cultivar	P = 0.0113	Storage time	P < 0.001
Sed cult	= 1.47		
Sed stor	= 0.261	Interactions	
Sed cult*stor	= 1.57	Cult*Stor	P =0.426

Trial 9 Nairobi October 1998

Cultivar	4	8	12	16	Mean
Yanshu	4.52	7.15	8.48	9.54	6.80
Kemb10	8.33	15.1	19.6	23.8	15.1
KSP20	5.32	8.70	10.8	126	8.53
Pumpkin	6.59	11.0	13.5	15.4	10.7
SPK004	5.96	10.8	14.1	17.6	10.9
BP1-SP2	5.72	8.61	10.3	11.6	8.32
Caplina	6.45	10.2	12.2	13.6	9.70
Salyboro	7.07	11.5	14.1	16.0	11.1
Yarada	8.99	14.8	18.2	21.0	14.3
Julian	8.31	13.3	16.4	19.0	13.1
Kihoro (potato)	1.01	1.42	1.71	1.95	1.41
Nyaya (potato)	4.10	6.0.7	7.01	7.88	5.78

Cultivar	P < 0.001	Storage time	P < 0.001
Sed cult	= 2.21		
Sed stor	= 0.282	Interactions	
Sed cult*stor	= 2.39	Cult*Stor	P < 0.001

Trial 10 Nairobi Nov-Dec 1998

Cultivar	8	26	41	Mean
Yanshu	6.2	9.6	12.6	9.48
Kemb10	10.8	20.7	26.9	19.5
KSP20	8.1	14.6	22.0	14.9
Pumpkin	9.2	15.4	18.4	14.3
SPK004	10.4	22.9	31.4	21.6
BP1-SP2	11.0	17.0	20.7	16.2
Caplina	7.5	11.0	16	11.5
Salyboro	12.2	20.2	24.0	18.8
Yarada	17.6	28.9	34.6	27.0
Julian	15.6	29.3	37.5	27.5

Cultivar	P < 0.001	Storage time	P < 0.001
Sed cult	= 2.2		
Sed stor	= 0.509	Interactions	
Sed cult*stor	= 2.59	Cult*Stor	P < 0.001

Table 3.6 c Weight loss during storage for 10 sweet potato cultivars and 2 potato cultivars grown in Kenya. The significance levels of cultivar, storage time and their interactions in trial 11.

Trial 11 Nairobi Nov 1998

Cultivar	4	8	12	19	Mean
Yanshu	5.19	7.03	8.11	9.52	7.13
Kemb10	6.09	9.04	11.3	14.9	9.85
KSP20	4.72	6.47	7.79	9.83	6.90
Pumpkin	4.60	6.41	7.87	9.84	6.89
SPK004	5.31	8.22	10.6	14.55	9.18
BP1-SP2	4.81	6.33	7.27	8.58	6.47
Caplina	5.23	7.02	8.06	9.51	7.13
Salyboro	5.28	7.50	9.01	11.2	7.90
Yarada	7.79	10.9	12.8	15.5	11.2
Julian	7.32	9.93	11.8	14.7	10.5
Kihoro (potato)	2.80	3.45	4.01	4.69	3.59
Nyaya (potato)	5.33	6.74	7.70	9.07	6.95

Cultivar	$P < 0.001$	Storage time	$P < 0.001$
Sed cult	= 1.313		
Sed stor	= 0.148	Interactions	
Sed cult*stor	= 1.40	Cult*Stor	$P < 0.001$

The cultivars showed significant differences in weight loss for all the trials. Probability levels of $P < 0.001$ were obtained in most cases and $P < 0.05$ in trial 5, 7 and 8. The differences among cultivars were generally consistent. For the five cultivars common to all trials, weight losses of SPK 004 and Kemb10 were always high and the lowest weight losses were obtained from the cultivars Yan Shu 1 and KSP 20. Consistent differences were also observed among the extra five cultivars in trial 7, 9, 10 and 11 (BP1-SP2, Caplina, Salyboro, Yarada and Julian). Julian and Yarada always showed the highest weight loss, whereas the weight loss of BP1-SP2 and Caplina was low. Zapallo was exceptional and is discussed below. It should be noted however that the weight losses in trial 7 were much higher than in trial 9, 10 and 11 (Compare Fig 3.4e with 3.4g and 3.4i). This can probably be explained by the fact that the roots came from different experiments and hence harvesting and handling practices differed. This emphasises how important handling can be for shelf life.

Most of the weight loss curves showed a decrease in steepness during storage, indicating a decline in rates of weight loss. It was noted that reduction in steepness was more pronounced for the cultivars Yan Shu 1 and KSP 20 than for SPK 004. The lowering of the rates of weight loss are likely to be due to the wound-healing process and periderm formation under damaged areas (see Chapter 6). Linearity in weight loss during storage was also observed during storage of potatoes at high temperature by Kang *et al.,* (1993). Further Passam *et al.,* (1976) found that linearity of weight loss occurred especially for yams that were bruised.

Kemb 10 and SPK 004 lose weight more rapidly and this was also observed as visual shrivelling during the trials, starting normally at the ends of the root (see Plate 3.2). This phenomenon has been described as 'tissue collapse'. Small roots are found to be more susceptible to this kind of desiccation than large roots (Jenkins, 1982). The observations in these trials confirmed those results.

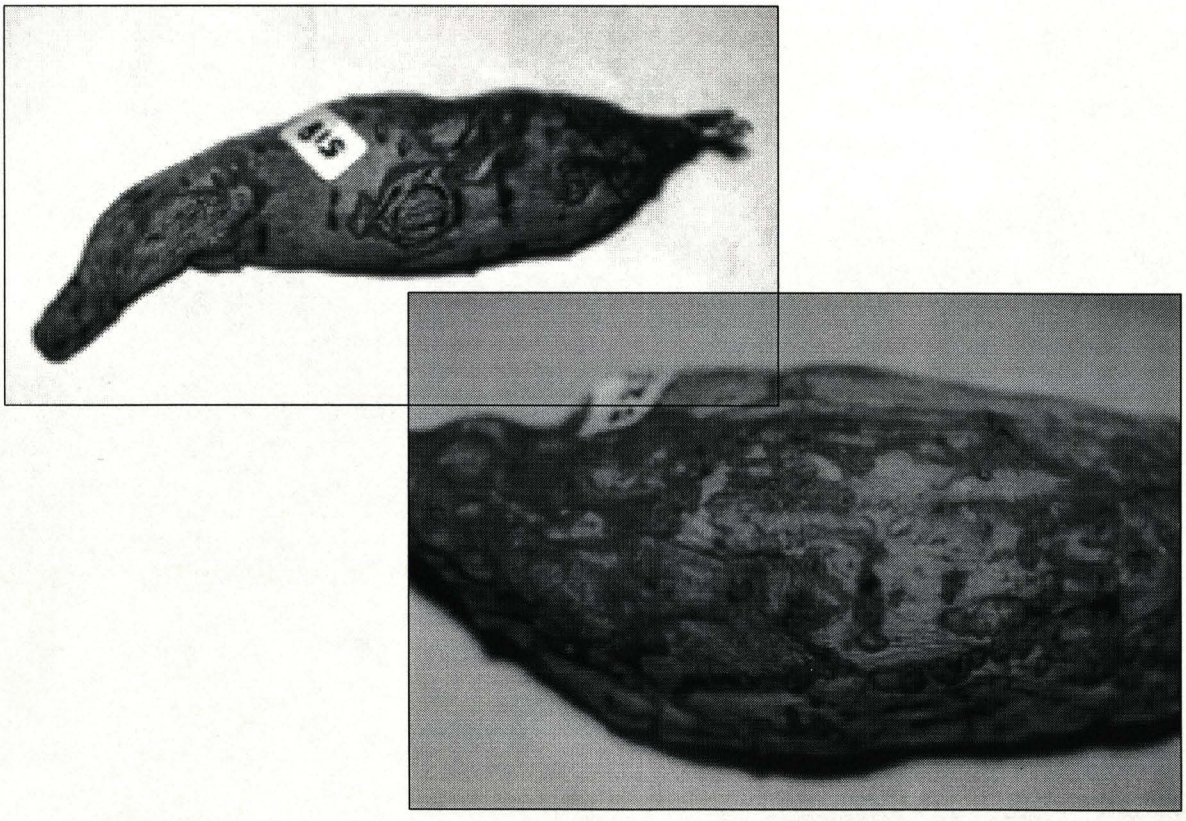


Plate 3.2 Shrivelling of sweet potato roots. Both roots from the cultivar SPK 004.

The rates of weight loss recorded are in general very high compared to rates that have been recorded in temperate areas like the United States, but they are in agreement with findings from other scientists investigating shelf life of potatoes and sweet potatoes under tropical conditions.

Although the weight loss assessments were carried out with the same cultivars, there were substantial differences in weight loss among the trials. One of the five cultivars, Zapallo, behaved unpredictably, having a low weight loss in trial 1 and 2, but high weight losses in trial 5, 6, 8 and 10. It is not exactly clear why Zapallo behaved inconsistently, but it was observed that the skin of the Zapallo roots in trials 5, 6, 7 and 8 was much rougher than in trial 1 and 2. This was thought to be due to the higher number of lenticels as will be discussed in Chapter 4.

3.4.4 Comparison of weight loss in Tanzania and Kenya

During storage experiments at Ukiriguru with Tanzanian cultivars (trial 3) all cultivars had extremely high weight losses, varying from 8.4 to 30.6% during two weeks storage. For roots grown in Kenya the weight losses varied between 3.9% and 18.2% for a similar storage time. The large differences in weight loss between these countries are probably due to the difference in climate. The relative humidity in the Lake zone in Tanzania was as low as 55% while in Kenya the relative humidity varied between 65 and 75%. Since all the storing systems were effectively open (open polythene sacks, and open crates) the climate plays an important role. Measurements of the relative humidity too close to the roots could give a false indication of the conditions the roots respond to. Furthermore, pre-harvest conditions, such as drier soil in Tanzania, could play a role. Other post-harvest factors, such as handling, could also have affected the shelf-life.

3.4.5 Relationship between weight loss and rotting

In trial 3 measurements showed that weight loss and rotting were significantly related. Figure 3.5 shows the correlation between weight loss and rotting and their significance levels and correlation coefficients.

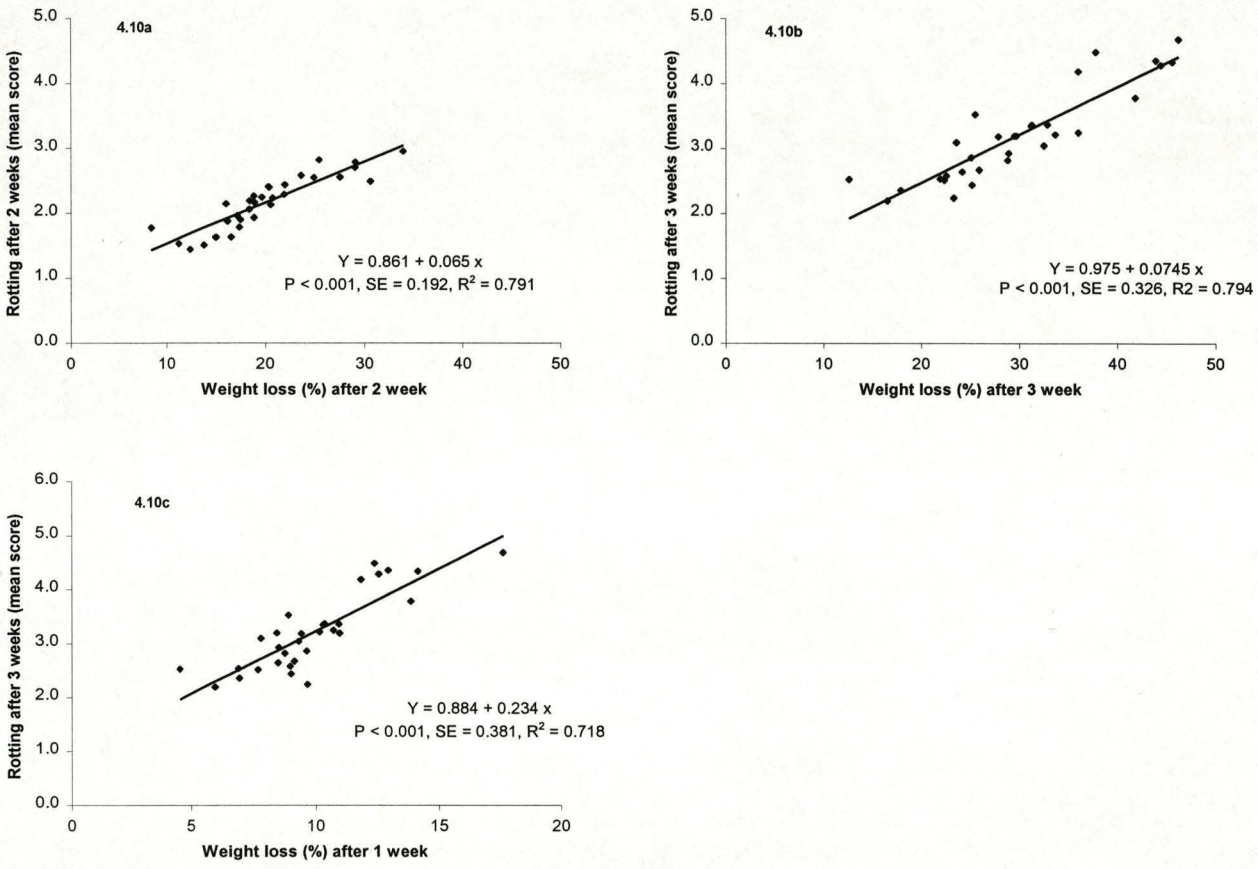


Figure 3.5 a-c The relationship between mean scores of rotting and mean weight loss of 29 sweet potato cultivars after 2, 3 weeks storage under marketing conditions in Tanzania. C) presents the relationship between weight loss after 1 week and rotting after 3 weeks.

Significant relationships were found between weight loss and rotting after 14 and 21 days. The correlation coefficients varied between 0.92 and 0.98 with a significance level of $P < 0.001$. Also the relationship between weight loss after 1 week and rotting after 3 weeks was significant with a correlation coefficient of 0.85 and the significance ($P < 0.001$) suggesting that there is a causative link between weight loss and rotting.

3.4.6 Relationship between weight loss and sprouting

Sprouting occurred during some of the storage trials. Figure 3.6 presents the percentage of the sprouted roots in trial 2 after 13 days and longer periods. It was observed that the roots of cultivars Kemb 10 and SPK 004 had sprouted less than the cultivars KSP 20, Yan Shu 1 and Zapallo. The sprouting cultivars correspond with the cultivars that had the lowest weight loss. It seems that desiccation is bad for sprouting.

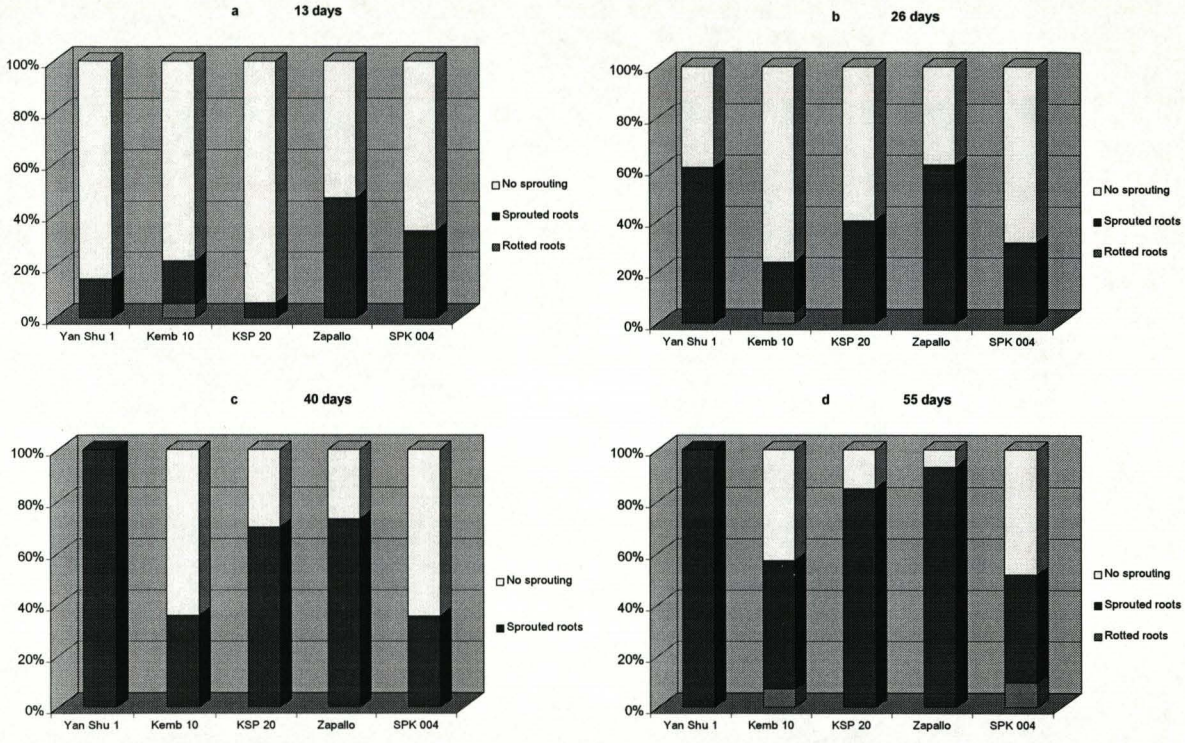


Figure 3.6a-d Percentage of sprouted sweet potato roots after 13, 26, 40 and 55 days of storage under simulated tropical conditions during trial 2 (T = 26.1°C, RH = 73.2%)

3.4.7 Relationship between weight loss and marketability

An illustrative experiment was carried out to assess the appearance of stored sweet potatoes. The roots of storage trial 10 were assessed by a Kenyan house wife for their saleability. Figure 3.7 presents the percentage of the roots that were saleable after 8 weeks of storage under local storage conditions in Nairobi. The best performing cultivar was Yan Shu 1 of which 96% of the roots were saleable. Most of the roots of Caplina, KSP20 and Zapallo were also saleable, but at lower price. The cultivars Yarada, SPK004 and Kemb10 had the largest quantity of non saleable roots after 8 weeks of storage. It seemed that saleability was strongly related to the amount of weight loss as is shown in Figure 3.8.

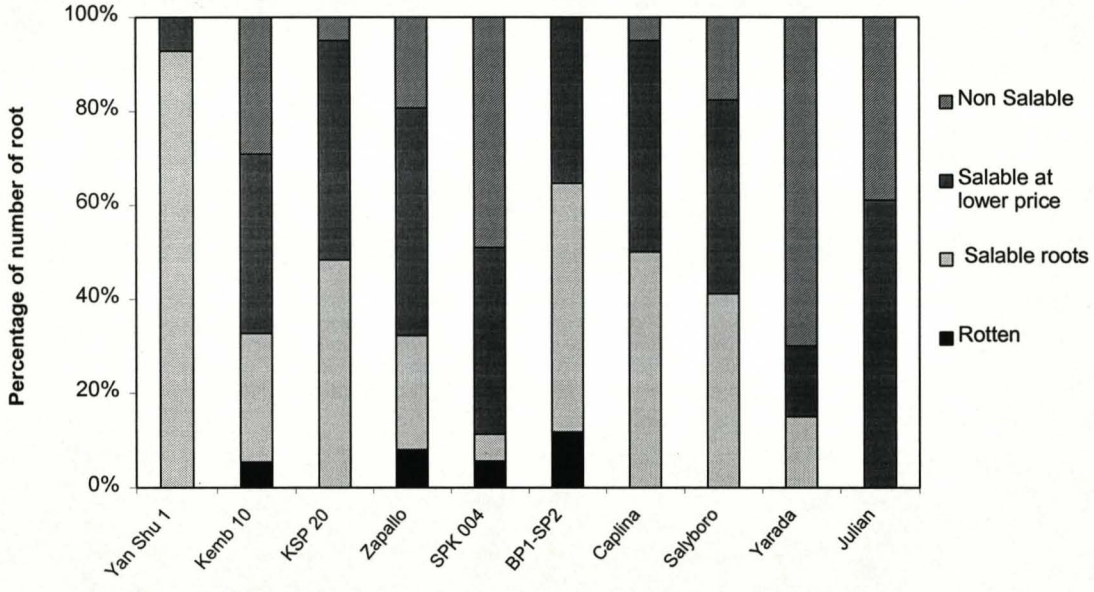


Figure 3.7 Percentage of roots of 10 sweet potato cultivars that are saleable after 8 weeks of storage at NARL, Nairobi Kenya.

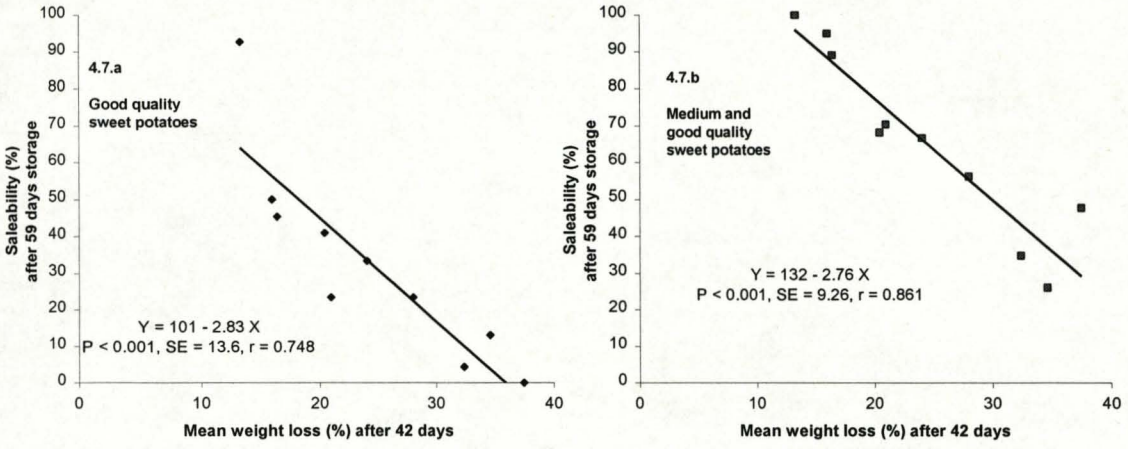


Figure 3.8a-b Relationship between the percentage saleable roots (according to a Kenyan housewife) and mean weight loss. [a] presents good quality roots, and [b] presents medium and good quality roots. Each point represents saleability and weight loss of one cultivar.

Unfortunately weight losses could not be recorded on the day of saleability assessment, which was 59 days after harvest. The weight losses in the Figures are therefore based on the weight loss at 42 days after harvest.

Non saleable roots had a weight loss mean of 35.3%, whereas the mean weight loss of saleable roots was 13.6%. These results confirm that weight loss is an important measure for storability. From these results it can be estimated that roots that have lost less than 20% of weight are still saleable, but if weight loss exceeds 35% of its initial weight, sweet potato roots become unmarketable.

3.5 Summary and conclusions

3.5.1 Summary of findings

- The weight losses of sweet potato when stored under tropical conditions were high and ranged from 5 to 15% per week.
- There was a large range in weight loss among sweet potato cultivars, and the differences were consistent ($P < 0.001$ for most trials).
- Cultivars with good storability were the cultivars Yan Shu 1, KSP 20, BP1-SP-2 and Caplina (from Kenya), and Bilagala, Kagole and 440088 (from Tanzania).
- Cultivars grown and stored in Tanzania were more susceptible to weight loss than cultivars grown in Kenya, which might be due to the differences in climate with a lower RH in Tanzania.
- Significant differences were found among cultivars in their rate of respiration. Although the rate of respiration correlated with the rate of weight loss ($P = 0.001$), respiration contributed only 5 to 15% of the total weight loss.
- Roots with high rates of weight loss were more susceptible to rotting under the conditions tested.
- Sprouting occurred especially in cultivars with low weight loss.
- Marketability of sweet potatoes was related to weight loss. Roots with a weight loss up to 20% were still marketable, but if weight loss exceeded 35% they become unsaleable.

3.5.1 Conclusions

- Weight loss is the key factor in perishability of sweet potatoes that are stored under tropical conditions.
- The large range in weight loss indicates that there is potential for extension of shelf-life by cultivar selection
- Since weight loss was mainly due to water loss, storability could potentially be increased by reducing the rate of water loss

Chapter 4

Skin characteristics and root surface area

4.1 Introduction

In Chapter 3 it was established that weight loss is a key factor in perishability. Differences in weight loss exist among sweet potato cultivars and most of the weight loss consists of water loss rather than losses due to respiration (< 20%). In this, and subsequent chapters the question as to why cultivars differ in weight loss and storability will be addressed. This chapter concentrates on two structural components of intact roots that might affect the storability.

Firstly the total root surface area in relation its weight could play a role. A high surface area/ mass ratio would result in a higher water loss, as has been reported for other horticultural produce (Diaz-Pérez, 1998). Secondly the structure of the periderm, which forms the main barrier against water loss between internal tissue and the environment, might affect storability.

The objectives of the research in this Chapter were therefore to explore the cultivar variation in size and the surface area/ mass ratio of sweet potato roots, and to relate these characteristics to storability. The thickness and physiology of the periderm were studied and compared with properties of potato periderm. The permeability of the native periderm was also assessed.

4.2 Literature review

4.2.1 The effect of surface area on weight loss

Weight losses expressed as percentage of initial weight may be misleading if the comparison is made between produce of different sizes or shapes. Transpiration is a function of the surface area (Burton *et al.,* 1992) therefore in products with identical transpiration rates, large products have a lower percentage weight loss than small products. Thus for other horticultural produce, such as tomato, pepper and egg plant it has been reported that large fruits have lower percentage weight losses, partly due to the lower surface area/ mass ratio (Diaz-Pérez, 1998). The surface area /mass ratio is undoubtably affected by the shape of roots and the shape is therefore an important factor to include in this study. Shape and size can also be important in relation to susceptibility to mechanical damage, but these aspects will be investigated in Chapter 5.

4.2.2 Periderm characteristics

Sweet potato periderm consists of 4 to 10 layers. The periderm thickness is thought to depend on the rate of cork production and loss of surface cork through root enlargement and decay. The periderm can vary in its thickness within the roots according to the degree of russetting (Morris and Mann, 1955).

Little research has been carried out specifically on the characteristics of the sweet potato periderm, but the information available on periderm of potato tubers can serve as useful background information. It should, however, be taken into account that sweet potatoes have a different origin in the plant; the former are roots and differ substantially in anatomy and physiology from tubers, which derive from the stem (Kays, 1985).

The potato periderm is composed of phellem, phellogen and phelloderm tissues. The phellem consists of corky suberized cells on the surface and constitutes the 'skin' or periderm. The cells may be arranged in a regular stacking pattern. The phellogen tissues, also called cork cambium or transition zone comprise the next layers of cells, generally between 2 and 4 layers. These cells actively divide to form the phellem cells on one side and the phelloderm, a group of specialised parenchymal cells (Muir and Bowen, 1994; Reeve *et al.,* 1969).

When the periderm matures and the skin sets, it achieves low permeability and the phellem, and adjoining tissues become tightly bonded to each other and firmly attached to adjacent underlying cortical cells (Lulai and Orr, 1994; Muir and Bowen, 1994). Cell walls of the phellem become laminated with suberin, which protects the tuber from water loss and disease (Vaughn and Lulai, 1991). Kolattukudy (1984) postulated a layered model consisting of phenolic components esterified with aliphatic components and covalently attached to the phellem cell walls. Interdispersed in the aliphatic region of the suberin biopolyester are waxes, fatty acids and fatty alcohols. These compounds provide resistance to water vapour conductance from storage organs (Soliday *et al.,* 1979). The amount of wax in the periderm may range from 2 to 32 $\mu g \cdot cm^{-2}$ (Espelie *et al.,* 1980).

The permeability through native periderm may vary with to the maturity of potato tubers. Luali and Orr (1994) developed a technique to quantify native periderm permeability in potatoes using a porometer. They found that the skin of mature potato tubers allows the loss of approximately 0.005 mol of water vapour$\cdot m^{-2} \cdot s^{-1}$ native periderm surface, while the permeability for immature tubers could be 28 times as high.

Potato skin consists of 5-15 layers (Vogt *et al*, 1983) and the thickness ranges from 70 to 200 μm depending on cultivar (Muir and Bowen, 1994, Frydecka-Mazurczyk *et al.*,1990). Confusingly, Frydecka-Mazurczyk *et al.,* (1990) found that potato periderm thickness is positively correlated with natural weight loss. Table 4.1 presents a summary of their results.

Table 4.1 Some characteristics of different cultivars of potatoes stored for 6 months.

Periderm thickness (μm)	Weight loss (%)	Number of cultivars	DM content (%)	Starch content (%)
80-109	5.8	4	20.2	12.9
110-133	9.1	24	21.3	13.8
134-165	11.5	18	24.0	16.1
166-200	13.3	2	27.8	18.7

Data sourced from Frydecka-Mazurczyk et al., 1990

The thickness of the periderm is known to affect the water permeability for some other commodities. Water loss of apples was primarily related to skin characteristics, such as the thickness, the epidermal wax and the number of lenticels (Bebic, 1972). Lenticels can be described as openings in the periderm which form pathways along which micro-organisms and water vapour can easily migrate (Adams 1975, Adams and Lapwood, 1978).

This chapter will investigate the cultivar variation in periderm thickness and permeability and the cultivar differences in physical properties of the roots such as shape and surface area/mass ratio.

4.3 Materials and methods

All experiments in this Chapter were carried out upon roots from trials 7, 8, 9, 10, 11, 12 and 13. More detailed information on the trials and storage conditions is given in Chapter 2. Table 4.2 presents an overview of the experimental design.

Table 4.2 Overview of experiments to investigate the role of physical and periderm characteristics involving 10 sweet potato cultivars and 2 potato cultivars.

	Type of experiment							
	Root dimensions; length; circumference; shape		Water loss through undamaged periderm (porometer)			Periderm thickness		
	No. roots per cultivar	No. of cultivars	Storage time (days)	No. roots per cultivar	No. of cultivars	Storage time (days)	No. roots per cultivar	No. of cultivars
Trial 7	29	10	6, 8	6 6	10 10	6, 8	1 1	10 10
Trial 8	77	5	1, 3, 5, 7	9	5	1, 3, 5, 7	3	5
Trial 9						0, 3, 8, 10, 13 6	1 5	4 10 + 2 potato
Trial 11						6	1	10 + 2 potato
Trial 12	16	9						
Trial 13	60 [1)]	9						

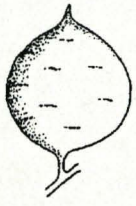
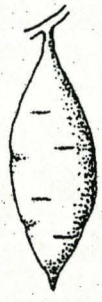
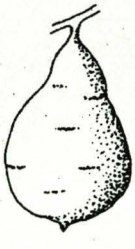
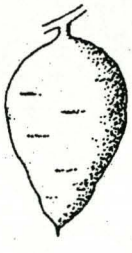
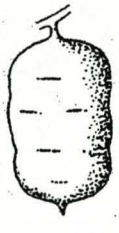
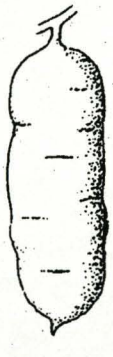
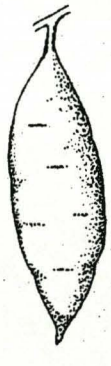
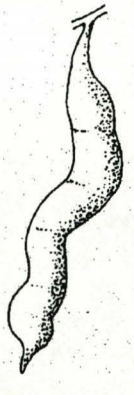
1) except for Zapallo for which 24 roots were assessed and Kemb 10 for which the sample size was 40 roots

4.3.1 Physical characteristics

4.3.1.1 Shape

The shape for each sweet potato root in trial 7, 8, 12 and 13 was scored according to standard descriptors (CIP/AVRDC/IBPGR, 1991) and ranged from 1 to 9, in which score 1 represents 'round' and score 9 represents 'long irregular curved'. The descriptors used are presented in Table 4.3. Numbers of shapes occurring within each cultivar were counted, and cultivar effects were analysed as a contingency table in Genstat using a χ-square test (Mead *et al.*, 1993).

Table 4.3 Roots shapes

 **1. Round** Almost circular outline with a length/ breadth (L/B) ratio of about 1:1	 **2. Round elliptic** A slightly circular with acute ends. L/B ratio not more than 2:1	 **3. Elliptic** Symmetrical outline with about maximum breadth at equal distance from both ends which are slightly acute. L/B ratio not more than 3:1
 **4. Ovate** Outline resembling the longitudinal section of an egg. The broadest part is at the distal end (i.e. away from the root stalk.	 **5. Obovate** Inversely ovate outline. The broadest part is at the proximal end (i.e. close to the root stalk)	 **6. Oblong** Almost rectangular outline with sides nearly parallel and corners rounded. L/B ratio about 2:1
 **7. Long oblong** Oblong outline with a L/B ratio of more than 3:1	 **8. Long elliptic** Elliptic outline with a L/B ratio of more than 3:1	 **9. Long irregular or curved**

Source: CIP, AVRDC, IBPGR. 1991

4.3.1.2 Size

Size volume is defined as mass / density, the size of the roots was estimated by their mass (or weight), based on the assumption that the density of sweet potato is approximately 1 kg · litre $^{-1}$ mass of a root = volume * density.

4.3.1.3 Surface area/ mass ratio

Determining skin surface area accurately is difficult. Some destructive methods have been developed e.g. peeling of the skin after which the surface area of the peel was determined using photography (Diaz-Perez, 1998), the use of adhesive tape (Banks, 1985), or the use of ink or methylene blue (Sattelmacher *et al.*, 1983). But since the roots were also needed for storage trials, destructive methods were inappropriate. A non destructive method has been described which uses a digital image analysis system (Wright *et al.*, 1986) which was not available for this project.

For the trials presented in this Chapter the surface area was therefore estimated from length and circumference using the equation of a perfect ellipsoid (Dr J.S. Rees, personal communication).

$$A = 1/c^* \, 2\pi a^2 b \, (\sin^{-1}(c/a) + (bc)/a^2) \qquad [cm^2]$$

In which:

A = *Surface area* $[cm^2]$

a = ½ * *length of root [cm]*

b = ½ * *diameter of the root [cm] = circumference/* $2^* \pi$

$c^2 = a^2 - b^2$

Roots were weighed and the surface area /mass ratio was then calculated (Diaz-Perez, 1998) and correlations to the rate of weight loss using linear regression carried out in GENSTAT.

4.3.2 Measuring characteristics of undamaged periderm

4.3.2.1 Sample preparation

Fixing samples

Tissue blocks measuring approximately 7 x 7 x 7 mm^3 were cut from the root surface and fixed in an FAA solution (Ethanol 70%, Formalin 5%, Acetic Acid 5%). The tissue blocks were stored in scintillation vials (24 ml, Merck, UK) until needed (at least 24 hours).

Embedding

The tissue blocks were dehydrated in a series of ethanol (methylated spirit, BDH) and toluene (99%, BDH) as presented in Table 4.4. They were then embedded in paraffin wax (Paraplast Plus, Sigma) which was maintained at 65°C in an oven during the embedding. The volume of the ethanol, toluene and wax used was at least 20 times the volume of the sample.

Table 4.4 Dehydration and embedding series for sweet potato cubes (0.34 cm^3). The volume of liquid was at least 20 cm^3.

Time of immersion	Day 1	Time of immersion	Day 2
> 24 hours	FAA solution	2 hr	Paraffin wax (65°C)
2 hr	90% ethanol/water	2 hr	Paraffin wax (65°C)
2 hr	100% ethanol	2 hr	Paraffin wax (65°C)
2 hr	100% ethanol		Paraffin wax in weighing boats
2 hr	100% toluene		
2 hr	100% toluene		
Overnight	100% toluene		

The embedded tissue blocks were cooled to 10°C and sections (10 μm) were cut using a bench top Microtome. The sections were floated onto a gelatin adhesive solution (1%) at 50°C and mounted onto glass slides. All slides were left to dry overnight on warmed plates (40°C).

4.3.2.2 Staining

Prior to staining, the sections were deparaffinised in toluene 100% (2x), and rehydrated in a graded ethanol series (2x 100%, 90% and 70 %, 10 minutes per step).

Sudan III

Sections were stained overnight in a saturated solution of Sudan III (Sigma) in 70% ethanol. The sections were covered with aquamount (BDH) while still moist and a coverslip was applied.

Safranin – Fast Green

Sections were stained in aqueous safranin (1%) for 45 minutes. The sections were rinsed in water, and stained with fast-green for 10 seconds, followed by a dehydration series (ethanol 70%, ethanol 90%, 2x ethanol 100%, 2 x toluene 100%). A coverslip was applied using DPX adhesive (Sigma).

4.3.2.3 Microscopy

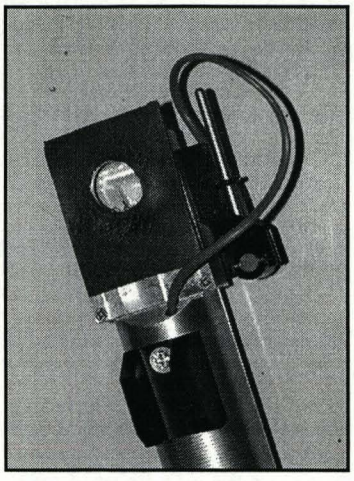
The embedded sections were examined using a Leitz Laborlux K microscope fitted with a Ploempak fluorescence illuminator. Leitz filter blocks A and I_2 were used for excitation. Filter A consists of an primary exciting filter BP 340 –380 nm, a beam splitter RKP 400 and a barrier filter LP 430. Filter I_2 consists of a exciting filter BP 450-490 nm with a RKP 510 beam splitter and suppression filter of 515. Micrographs were taken using a Minolta X-700 camera.

4.3.2.4 Thickness and number of periderm cell layers, measured from fresh sections

The periderm thickness and number of periderm cell layers in trial 7 and 8 were assessed from hand-cut sections. The sections were cut transversely using a razorblade (Wilkinson, Boots). They were washed in a dilute iodine (I_2) solution for approximately 3 minutes to enhance the contrast between cortex and periderm (Andrew Muir, personal communication). A Leitz Dialux 20 microscope (Leica Ltd, UK) equipped with a graticule (27 units = 100 μm) was used to measure the periderm thickness at 400 x enlargement. The number of periderm cell layers was also counted.

4.3.3 Moisture vapour conductance measured using a porometer

Transpiration rates through the native periderm of sweet potato roots were determined using a PP-systems porometer (PP Systems Ltd, Hitchin, UK). The leaf-chamber was adapted for this purpose by replacing the rectangular aperture with a round aperture (Plate 4.1) with a diameter of 1.5 cm. The lower clamp was removed and the head was padded with soft black foam to provide a seal and to avoid damage to the sweet potato surface during the measurements.



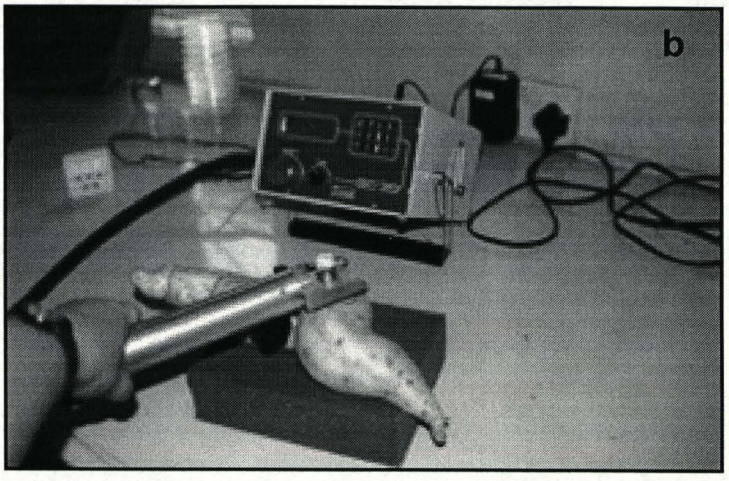


Plate 4.1 **a) Head of the porometer with round aperture and padding.**
b) Taking measurements upon sweet potato roots.

The **transpiration rate** was defined as:

$$E = (Ro-Ri) * Xs * V / (A * P)$$

in which E = Transpiration rate (mmol · m^{-2} · s^{-1})

Ro = Outlet air relative humidity (%)

Ri = Inlet air relative humidity (%)

Xs = Saturated water vapour pressure at the ambient temperature (mbar)

V = Flow rate of air through chamber (ml min^{-1} at 20°C & 1 bar)

A = Area of periderm exposed in the porometer (m^2)

P = Atmospheric pressure (mbar)

The mass flow rate (V) of the air through the chamber was set at 54.5 cm^3 · min^{-1}, the area of periderm exposed in the porometer (A) was 1.77 cm^2 and the atmospheric pressure (P) 1000 mbar.

The PP-Systems porometer handbook suggested the use of desiccant to lower the humidity of the in-going air (Ri) so that the out-going air has the same relative humidity as the environment. This would especially be important for leaf stomata which respond to the environmental conditions. However, the vapour conductance through sweet potato

periderm is a passive diffusion controlled process, and thus the use of desiccant was not considered necessary. Ambient air with ambient humidity was used for inlet. Some variation existed between days and time of the day, but this did not affect the relative rates and differences tended to be small.

During trial 7 the transpiration rate of undamaged periderm was measured at day 6 and 8 for 10 cultivars, using 6 roots per cultivar and during trial 8 the transpiration rate was measured at days 1, 3, 5 and 7 for 5 cultivars using 9 roots. Once a steady reading was obtained, generally after about 2 to 3 minutes, five measurements were taken at 15 sec intervals. The mean values of these readings were then calculated. The measurements were taken on areas of the native periderm with no visible damage and care was taken that no damage occurred during the measurement. The skin area used for measurements were marked, and these parts were used to assess periderm thickness (as described in 3.2).

4.3.4 Statistical analysis

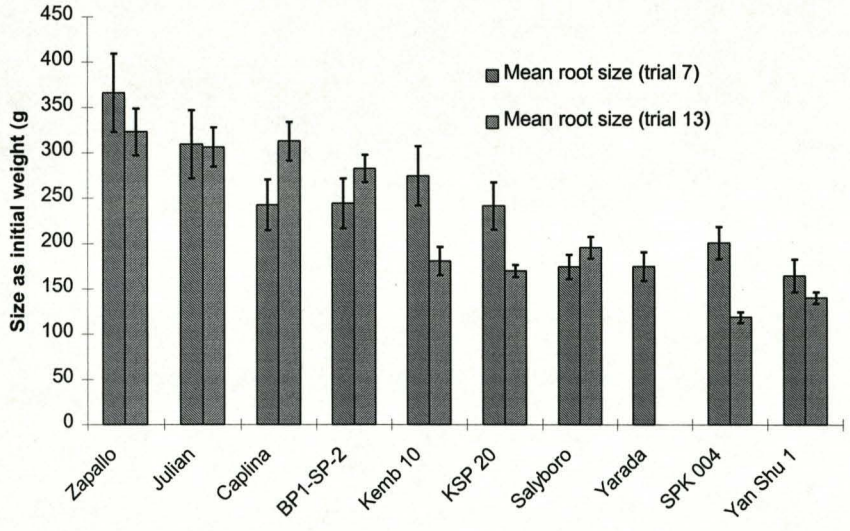
Analysis of the data was carried out in GENSTAT by analysis of variance and linear regression (Mead *et al.*, 1993).

4.4 Results and discussion

4.4.1 Cultivar differences in size and surface area/ mass ratio

4.4.1.1 Cultivar differences in size

There were large cultivar dependent differences in sweet potato root size (Fig 4.1). The mean root size varied from 150 g for Yan Shu 1 to 370 g for Zapallo. For some cultivars the size of the roots also varied considerably between the trials, but the differences were not consistent.



Note: Not enough roots for trial 13 for the cultivar Yarada

Figure 4.1 Histogram of root size (initial mass) of the cultivars in trial 7 and 13. The bars present the standard error of the mean.

4.4.1.2 Cultivar differences in shape

The shape of 1429 roots in total originating from trial 7, 8, 12 and 13 were scored according to standard descriptions (CIP, 1991). Figure 4.2 presents the distributions of the root-shape per cultivar. Generally there was a large variation in shape within each cultivar which was in contrast to popular cultivars in the US which are bred to have a uniform shape (Wright *et al.*, 1986). Around 56% of all the roots were long shaped i.e. length/width 3:1 while 11% of all roots was round shaped.

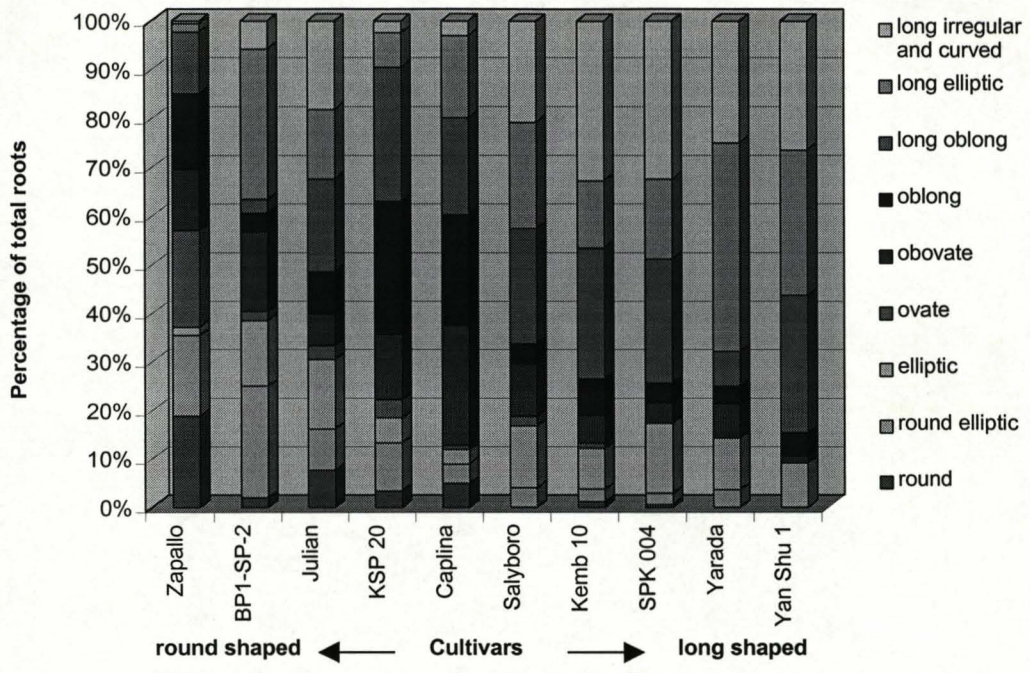


Figure 4.2 Distribution of root shapes of 10 sweet potato cultivars. The data were collected from Trial 7, 8, 12 and 13. Values were collected for at least 100 roots per cultivar, except Yarada: 28 roots

The contingency tables showed evidence that the shapes of the roots were related to the cultivar. The cultivars Salyboro, Kemb10, SPK004, Yarada and Yan Shu 1 were long in their shapes. Zapallo was the most round shaped cultivar. It is likely that the shape of sweet potatoes affects the surface area, and susceptibility to damage. The association between shape and susceptibility to damage is investigated in Chapter 5.

4.4.1.3 Surface area/ mass ratio and its role in storability

The surface area of each root was estimated by the equation of an ellipse, assuming that it was a perfect ellipsoid, using the length and diameter data of each root. The surface area/ mass ratio was related to the initial mass of the root ($P < 0.001$, R^2 adjusted 59.6%). Large roots generally had a relatively smaller surface area than little roots (Table 4.5, trial 7).

A linear regression analysis was carried out between the surface area/ mass ratio and the weight loss after 27 days (Table 4.5). Overall the surface area/ mass ratio did affect weight loss of the sweet potato roots. The linear regression analysis was significant in

both trial 7 and 8 ($P < 0.001$ and $P = 0.011$ respectively). However, the adjusted R^2 representing the percentage variability accounted for was low (17.1 and 1.3%). When cultivar was added as grouping factor to the model, the R^2 adjusted increased. In trial 7 more than 40% of the variability was explained by cultivar effect, and in trial 8 this was almost 40%. This means that weight loss and storability are not fully explained by the surface area/ mass ratio of the roots, but that other cultivar related factors must be taken into account.

Table 4.5 Significance levels of the regression between weight loss and rate of weight loss as explained by surface area/ mass ratio and grouping factor cultivar

	Regression model for explanatory value for	P value	R^2 adjusted (%)
Trial 7	Surface area/mass ratio explained by initial mass	< 0.001	59.6
Trial 7	Weight loss after 27 days explained by		
	◆ Surface area / mass ratio	= 0.011	1.3
	◆ Surface area /mass ratio + Cultivar	< 0.001	40.5
	◆ Surface area /mass ratio + Cultivar + Suma*Cult [1)]	< 0.001	40.8
Trial 8	Weight loss rate at day 7 explained by		
	◆ Surface area / mass ratio	< 0.001	17.1
	◆ Surface area /mass ratio + Cultivar	< 0.001	38.4
	◆ Surface area /mass ratio + Cultivar + Suma*Cult [1)]	< 0.001	45.7

1) Suma = Surface area/ mass ratio; Cult = cultivar

4.4.2 Periderm characteristics

4.4.2.1 Periderm characteristics of sweet potato in comparison with potatoes

Sections of sweet potato stained with safranin – fast green were investigated by UV microscopy. The periderm could easily be distinguished from surrounding tissue by its blue fluorescence. Epidermal cells are known to fluoresce blue in onion (McLusky *et al.*, 1999) and apple (May *et al.*, 1998). The micrographs in Plate 4.2 show periderm of potato and sweet potato.

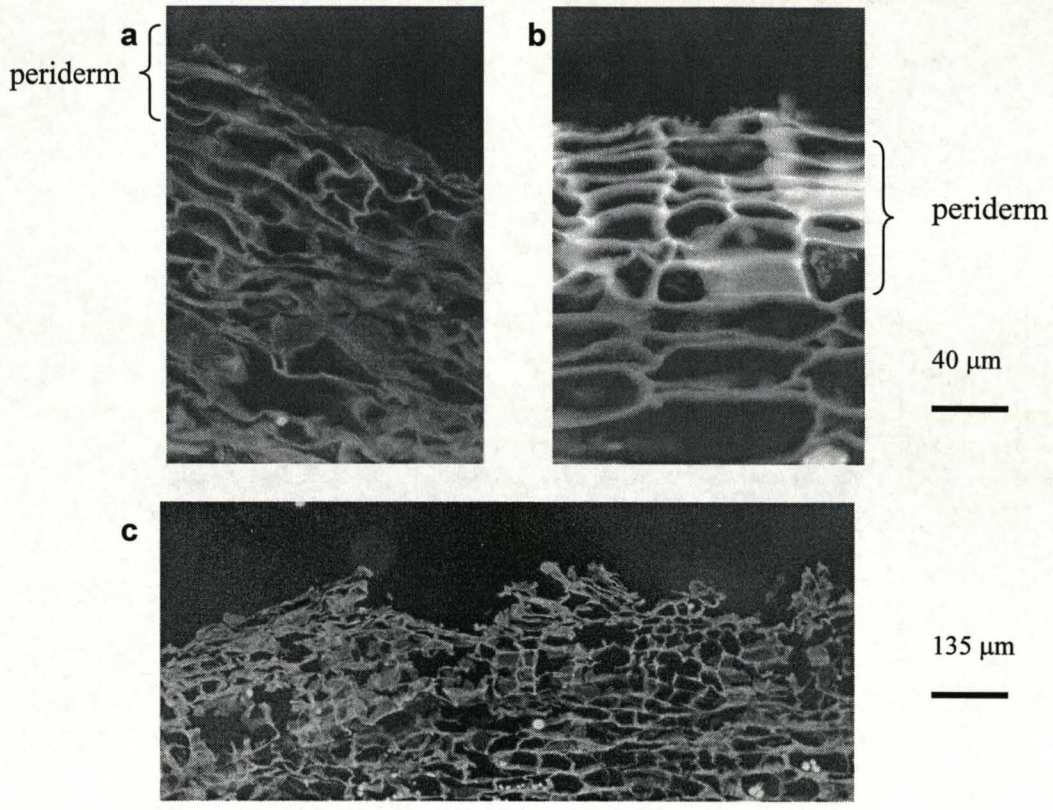


Plate 4.2 **a) sweet potato periderm (UV, 400x safranin/fast green stain)**
b) potato periderm (UV, 400x safranin/fast green stain)
c) rough surface of sweet potato skin (100x I_2 safranin/fast green stain)

Both potato and sweet potato periderm emitted a blue fluorescence which suggested that some of their components were similar. The blue fluorescence in potato was however stronger than in sweet potato. Some staining with Sudan III for suberin was also observed in both periderms, but was almost invisible and faded during long term storage so that it was impossible to determine quantities. Other scientists encountered similar difficulties with this stain (Vaughn and Lulai, 1991; Lulai and Morgan, 1992) or with Sudan IV (Southerton and Deverall, 1990). The reason here is possibly that during the embedding process the aliphatic domains of the suberin were somehow affected or extracted by the wax.

The tissue structure of sweet potato periderm was quite distinct from potato periderm. Potato periderm consisted of more cell layers which were flatter than those of sweet potato (Plate 4.2). Furthermore the surface of sweet potatoes appeared much rougher than the surface of potatoes, and contained more lenticels. Plate 4.2c illustrates this. Under the rough parts suberisation and lignification had occurred, often followed by a wound periderm. It was observed that the cultivar Zapallo had a large number of lenticels.

The embedded tissues looked similar to fresh hand cut sections. In hand cut sections the periderm distinguishes itself from the cortex by its cell shape and the starch content; periderm does not contain starch.

4.4.2.2 Periderm thickness and number of cell layers of sweet potatoes and potatoes

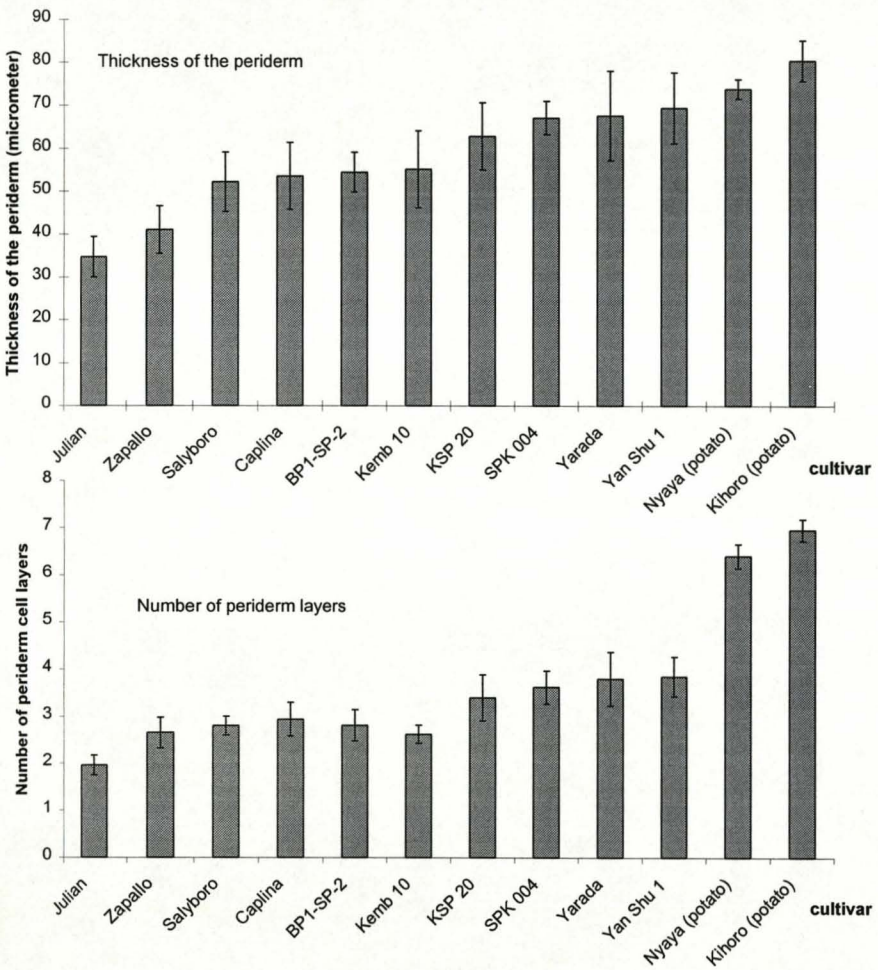
The thickness and number of cell layers of embedded periderm sections of 10 sweet potato cultivars and 2 potato cultivars are presented in Figure 4.3. The thickness of sweet potato periderm ranged between 35 and 70 μm and for potato it was between 74 and 81 μm. This is in agreement with findings in the literature for potato (70 to 200 μm, Muir and Bowen, 1994; Frydecka-Mazurczyk *et al.,* 1990, Vogt *et al.,* 1983). Within each sweet potato root there was a considerable variation in the thickness of the periderm. For sweet potato cultivars, thickness varied between 15 μm and 100 μm. In potato the thickness varied between 50 and 102 μm.

There were significant differences for periderm thickness among the sweet potato cultivars ($P < 0.001$). Yan Shu 1, Yarada, SPK004 and KSP 20 had the thickest periderm (63 to 70 μm), while the cultivars Julian and Zapallo had a relatively thin periderm (< 41 μm).

The number of periderm cell layers also differed significantly among cultivars ($P < 0.001$). The number of periderm cell layers was between 3.4 and 3.9 for the cultivars Yan Shu 1, Yarada, SPK004 and KSP 20, while the periderm of Julian was 2 cell layers thick. The potato periderm in contrast to sweet potatoes had more than 6 layers. The number of periderm cell layers related closely to the thickness of periderm for the sweet potato roots (R^2 adjusted = 0.882, $P < 0.001$). the number of periderm layers was found to be lower

than has been described by Morris and Mann (1955), who found thicknesses between 4 and 10 layers. Possibly the growing conditions in the tropics affect the thickness of the periderm, or the differences could be due purely to the fact that they are from different cultivars.

Figure 4.3 Periderm thickness (a) and number of periderm layers (b) for 10 sweet potato and 2 potato cultivars on day 6 after harvest. Each value is the mean of 5 roots, 4 readings each. Bars give the standard error of the mean. Data from embedded tissue samples from trial 9 and 11.



The thickness of one periderm cell layer was calculated by dividing thickness by number of layers. One periderm layer of sweet potato was almost twice as thick as a potato periderm cell layer (sweet potato 18 μm; potato 11.6 μm). There were however no significant differences in cell layer thickness among the sweet potato cultivars.

4.4.2.3 Thickness of sweet potato periderm during storage.

It was investigated whether the thickness of the periderm changes after harvest. During trial 8, the changes in periderm thickness were measured between 1 and 7 days after harvest for five sweet potato cultivars. (Table 4.6). There was no relationship between the number of cell layers and storage time (data not presented).

Table 4.6 The number of periderm layers and periderm thickness in relation to storage time and the significance of the regression between the two.

Cultivar	Number of periderm layers*	Periderm thickness at: Day 1	Day 3	Day 5	Day 7	**Means**
Yan Shu 1	4.4	83.2	60.8	69.6	70.4	**71.1**
SPK 004	3.8	77.2	63.2	70	51.6	**65.4**
Kemb 10	3.6	71.6	62.8	75.6	58	**67**
KSP 20	3.4	59.2	49.6	52.8	48.8	**52.2**
Zapallo	3.2	56.4	43.2	50	45.6	**48.8**
Means	**3.66**	**69.5**	**56**	**63.2**	**54.9**	**61**
	P < 0.001 LSD = 0.41	Cultivar: P < 0.001 LSD = 7.88		Day: P < 0.001 LSD = 7.04		

Periderm Characteristic	**MODEL DAYS as variate CULT as grouping factor**	**Percentage variance accounted for (R^2 adjusted)**	**Probability of the Model (P)**
Layers	DAYS	2.0	0.142
	DAYS + CULT	34.4	< 0.001
Thickness	DAYS	7.3	0.021
	DAYS + CULT	45.3	< 0.001
One layer	DAYS	5.8	0.036
	DAYS + CULT	38.3	< 0.001

** The number of periderm layers was the mean of all days*

The periderm thickness was highest at one day after harvest (mean 69.5 μm) and measured 56 μm after 3 days, 63.2 μm after 5 days and 54.9 μm after 7 days. The thickness of one periderm layer also decreased during storage (data not presented). Periderm thickness and thickness of one cell layer were significantly related to storage time (respectively P = 0.021 and 0.036). The decrease in cell thickness was probably due to water loss of periderm cells.

The results in Table 4.6 give further evidence of cultivar differences in periderm thickness ($P < 0.001$; LSD = 7.9). The significance of the cultivar effects also became apparent from the increase in R^2 adjusted. When cultivar was added to the regression model as a grouping factor the R^2 adjusted (= percentage variance explained by the model) increased with 38 and 33%. This indicates that periderm thickness was more cultivar dependent than storage time dependent.

4.4.3 Transpiration rate through native periderm

4.4.3.1 Transpiration of native periderm during skin-set

The transpiration rate through undamaged native periderm was measured using a porometer. Measurements were taken during trial 8 at day 1, 3, 5 and 7. Figure 4.4 presents the transpiration rate mean values per cultivar per day during the first week after harvest. Just after harvest (24 hr) the transpiration rate was high and varied between 25 to 53 mmol· m^{-2}· s^{-1} among the cultivars. It then dropped to 50% of its initial value by day 3 and decreased further on day 5 and 7, reaching levels between 12 and 18 mmol· m^{-2}· s^{-1} at day 7. These results are similar to the findings of Lulai and Orr (1994) measuring the transpiration of potato periderm. They found levels between 10 and 50 mmol· m^{-2}· s^{-1} on day 1, dropping to values around 8 mmol· m^{-2}· s^{-1} after one month.

Due to an inconstant magnitude of errors for residual values against fitted values, the data were transformed to *log (transpiration)* for the analysis of variance. The vapour conductance of cultivar Zapallo was significantly higher ($P < 0.001$) than for other cultivars. Cultivar differences were also found in trial 7 (Figure 4.5). The cultivars BP1-SP-2, Yarada and Julian displayed a significantly higher transpiration rate than the cultivars in trial 7A (Yan Shu 1, Kemb 10, KSP 20, Zapallo and SPK004).

The transpiration rates could **not** be extrapolated to water loss per root per day since the air in the cuvette is rapidly stirred by a mini-fan and greatly exceeds the flow rate through the cuvette (PP Systems, Porometer User Manual). The rapid air movement resulted in a decrease of the boundary layer, increases the vapour pressure deficit near the surface, and

so increases the rate of moisture loss (Wills *et al.*, 1998). The transpiration rate has therefore only a meaning for comparison of cultivars.

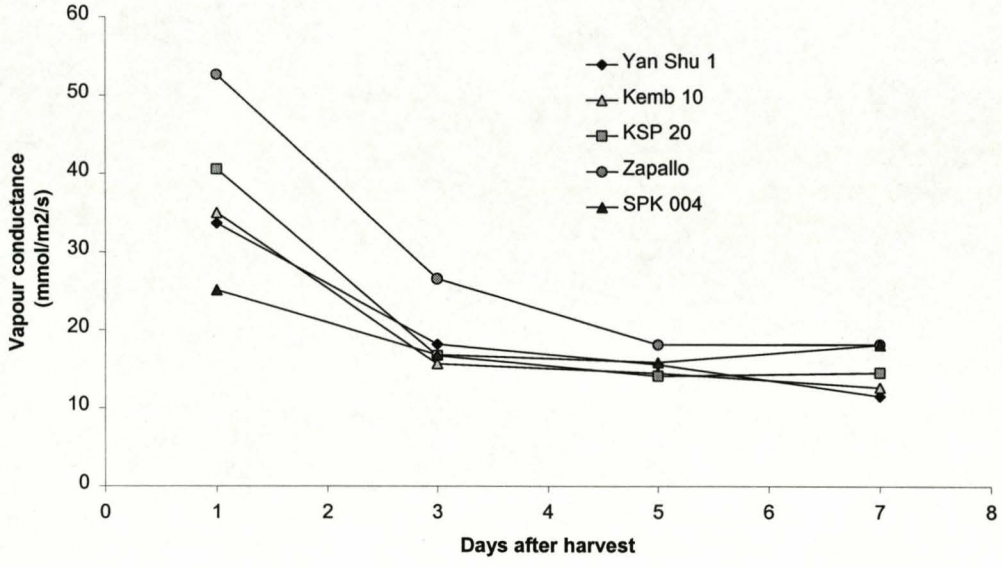


Figure 4.4 The effect of storage time on the water vapour conductance of native sweet potato periderm. Data come from Trial 8 and each value is the mean of 9 roots (LSD day 1 = 19.9; LSD day 3 = 3.1; LSD day 5 = 3.9; LSD day 7 = 6.5).

4.4.3.2 Lenticels

It was observed that Zapallo had a higher transpiration rate and also a higher density of lenticels than other cultivars. Lenticels form avenues for micro-organisms and water evaporation (Adams, 1975; Adams and Lapwood, 1978; Tyner *et al.*, 1997) and the density would affect the rate of water loss. Plate 4.3 shows a lenticel of the cultivar Zappallo. A suberised layer was present under the opening. Tyner *et al.*, (1997) found that although the zone of suberised cells under lenticels act to some extent as a barrier for water movement there was no clear relationship between permeability and suberisation. Hence a high density of lenticels is likely to increase the transpiration rate of a periderm.

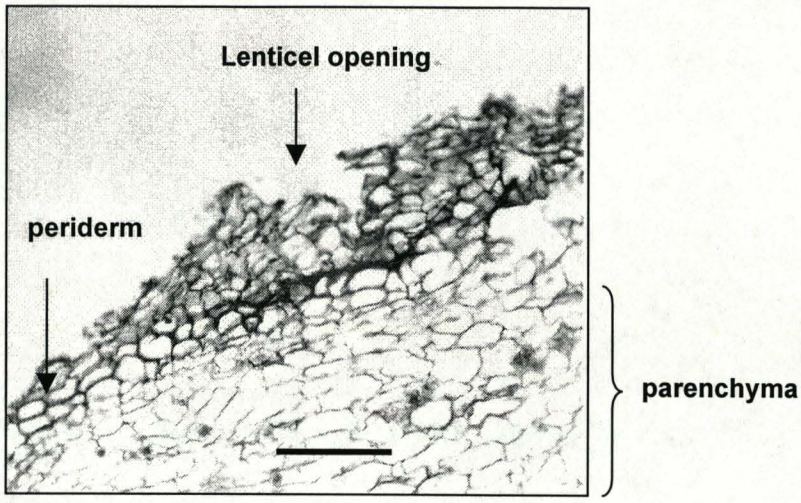


Plate 4.3 **Lenticel in Zapollo periderm at 4 weeks after harvest (Bright Field 100x enlarged (bar = 100 μm, section thickness 10 μm; stains: safranin/ fast green)**

4.4.4 Interrelationships between periderm thickness, transpiration and storability

4.4.4.1 Transpiration rate and storability

In Figure 4.5 the regression between weight loss and transpiration rate for the separate trials 7A, 7B and 8 are presented. Weight loss was not related to transpiration rate in any of the subtrials and it was concluded that cultivar differences in weight loss and storability were not purely due to the differences of transpiration rates through undamaged periderm.

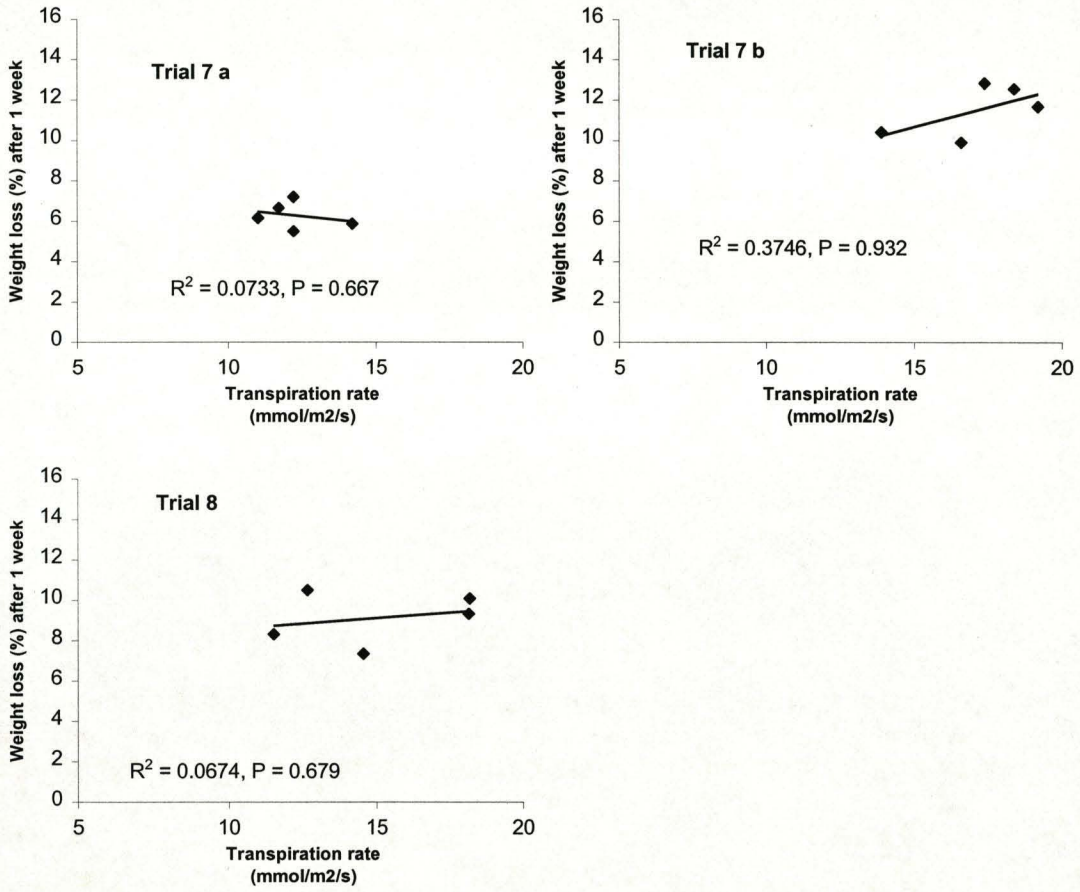


Figure 4.5 Regression analysis for the transpiration rate and weight loss during trial 7 and 8. Each point presents the mean of one cultivar at 8 days after harvest.

An important factor in storability may also be handling. The roots in trial 7A (Yan Shu 1, Kemb 10, KSP 20, Zapallo and SPK004) were harvested and handled as carefully as possible during harvesting, while the roots of trial 7B were subjected to some impact damage during yield measurements. Although the porometer measurements had been taken only on undamaged parts of the periderm, invisible damage such as internal bruises due to dropping, might have been the cause for the higher levels of transpiration. It is known that even if no visible damage marks are present, water loss through native periderm can be affected internal bruises (Lulai *et al.*, 1996). It was concluded that damage might play an important role in weight loss and further investigations on water loss caused by damage are presented in Chapter 5.

4.4.4.2 Periderm thickness in relation to weight loss and transpiration rate

Earlier it has been shown that cultivars differed significantly in periderm thickness and that significant differences existed in transpiration rate through native periderm. However, these two characteristics do not relate to each other (P= 0.198, Figure 4.6b). Neither do periderm thickness relate to weight loss data, and the regression between the two characteristics was insignificant (P= 0.223, Figure 4.6a). This means that there must be other factors involved than just periderm to explain differences in storability among cultivars.

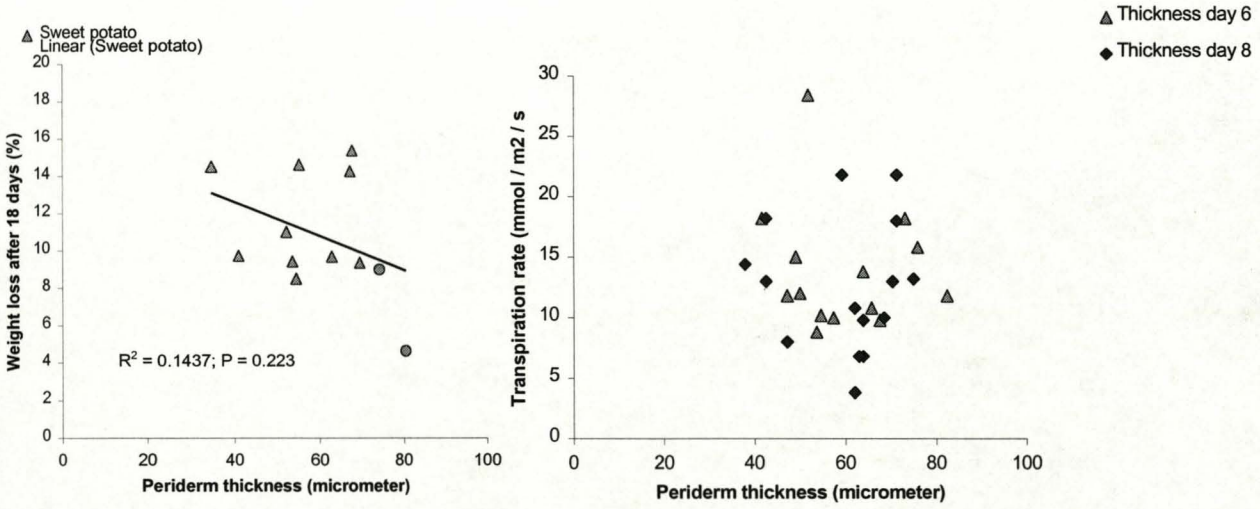


Figure 4.6 **a) Periderm thickness in relation to weight loss after 18 days (%). Each point represents one cultivar and is the mean of 5 roots**
b) Periderm thickness in relation to transpiration rates. Each value represents one cultivar, data were obtained from Trial 7.

4.5 Summary and Conclusion

4.5.1 Summary of findings

- There were significant differences among cultivars in root size. The surface area / mass ratio did relate to weight loss.
- Sweet potato cultivars differed significantly in their periderm thickness. The cultivars Yan Shu 1 and Yarada had a relatively thick periderm (63 to 70 μm and more than 3.8 cell layers) whereas the periderm of the cultivar BP1-SP2 and Zapallo was relatively thin (<41 μm and less than 2.8 cell layers). These results were consistent in two trials. The periderm got thinner during storage.
- Periderm thickness was not related to its permeability, but a slight trend was observed between periderm thickness and weight loss.
- The periderm of sweet potatoes was thinner than the periderm for potatoes, and consisted of fewer layers.
- The permeability for water vapour through undamaged periderm as measured with a porometer was between 25 and 50 mmol· m^{-2}· s^{-1} just after harvest and decreased during subsequent storage.

4.5.2 Conclusion

- The range in rates of weight loss can not be explained by root size and/or periderm structure. Periderm thickness therefore does not play a major role in sweet potato storability.
- There should be other cultivar related factors involved that affect weight loss, and the susceptibility to damage is likely to play a role.

Chapter 5

Susceptibility to damage

5.1 Introduction

In Chapter 4 it was established that cultivars differences in water loss for sweet potato are not due to differences in structure or the permeability of the native periderm. In this chapter the role of damage is investigated.

The storability of fresh produce is reduced by damage. Damaged areas form an entrance for micro-organisms and an avenue for moisture loss. Forms of damage that occur frequently are breaks, cuts or wounds, skinning injury and internal bruising. The latter is however difficult to assess from the outside (Wills *et al.,* 1998).

In Tanzania the sweet potatoes on the market often suffer from a considerable amount of damage (Rees *et al.,* 1998; Tomlins *et al.,* 1999a, 1999b). Most damage occurs during handling and transport. At present the marketing system for sweet potatoes in Tanzania has been poorly developed. To improve the shelf-life of sweet potatoes under marketing conditions, the susceptibility to damage should be taken into account. Lower

susceptibility could potentially reduce losses. There is evidence that susceptibility to damage is cultivar or variety dependent, as has been found for potatoes (Blight and Hamilton, 1974; Skrobacki *et al.,* 1989)

Susceptibility to skinning injury in potato can be reduced by removal of the green part of the plant some time before harvest. This induces pre-harvest skin-set (Bowen *et al.,* 1996). Some indication exists that pre-harvest pruning also has a beneficial effect on the susceptibility to skinning in sweet potato (Stikeleather and Harrel, 1990).

The objective of this chapter was to investigate whether sweet potato cultivars differ in susceptibility to damage and to see how damage relates to water loss. It was assessed whether damage relates to structural aspects of the root, such as shape and periderm thickness. The effect of pre-harvest pruning was also tested.

5.2 Literature review

5.2.1 Damage during marketing of sweet potato in Tanzania

In Tanzania sweet potatoes are traditionally handled and transported in polypropylene sacks which may weigh between 70 and 200 kg. The marketing systems are poorly developed which results in high levels of root damage. Kapinga *et al.,* (1997a) suggested that most of the damage occurs during handling and transport as opposed to harvesting.

Table 5.1 presents the occurrence of damage during different stages of transport. The most critical point in the transport system was during the loading and unloading of the sacks between the Lakeshore and port at Mwanza. At arrival on the market 17-21% of the roots may be broken, and 37 up to 86% may have skinning injury and 4% suffer from cuts.

Damage, and especially skinning injury, is likely to occur during the packing of the roots, when the roots are tightly stuffed into sacks (Plate 1.3b).

Table 5.1 Sweet potato (Polista) quality when handled and transported during the low and main seasons in the Lake Zone.

Root damage (total score)	Season	Stage in marketing chain			
		Farm	Lakeshore	Port (Mwanza)	Market (Mwanza)
		Total score (and per cent of roots with severe damage)*			
Broken roots	Main	4 (0)	7 (1)	43 (19)	40 (17)
	Low	16 (4)	20 (9)	33 (16)	44 (21)
Skinning injury	Main	22 (1)	30 (2)	85 (28)	89 (37)
	Low	21 (3)	70 (18)	118 (72)	133 (86)
Cuts	Main	6 (2)	9 (3)	17 (6)	13 (4)
	Low	9 (0)	8 (1)	15 (3)	16 (4)

**The total score is the sum of individual scores of 40 randomly selected roots. In brackets, the percentage of all 40 roots with severe damage (a score of three or greater), is indicated. Low season values are the means of 3 sacks and main season values are the means of 6 sacks.*
Table sourced from Tomlins et al., (1999a)

Tomlins *et al.*, (1999a) monitored the using impact data loggers and reported that consignments of roots can be subjected to 3 or 4 severe impacts during transport. An impact exceeding 10 g was referred to as 'severe impact', but might sometimes be as high as 30 g. An impact of 30 g corresponds with dropping roots from about 0.9 m, and 10 g corresponds with a drop of about 0.25 m. During transport, between 23 and 29 intermediate impacts were recorded measuring between 2 and 10 g. The number of minor impacts, between 0.2 and 2 g, was more than 1000. It was found that the large number of minor impacts correlated with skinning injury and breaks in the roots.

Although skinning injury can reduce the storability by increasing weight loss (Stikeleather and Harrel, 1990), in Tanzania the skinning injury has no effect on the value if the roots are marketed immediately. Breaks however can reduce the market value by 30% (Tomlins *et al.*, 1999b).

5.2.2 Measuring susceptibility to damage

Skinning injury

The level of skinning injury is reflected by elevated weight loss. On these grounds weight loss has been used as a measure of the degree of skinning injury (Stikeleather and Harrell, 1990).

The susceptibility to skinning injury for potatoes is traditionally measured using the 'thumb-test'. In this method pressure is applied with a thumb. Skin set is then classified as unset, mid-set or set (Bowen *et al.,* 1996). Based on the principle that both normal and tangential forces are required to remove the skin, Bowen *et al.,* (1996) and Muir and Bowen (1994) developed a scuff meter to measure the susceptibility to skinning. Another method is based on simulating the agitation during harvest and handling using a barrel. While the barrel is rotated tubers scuff to each other. The amount of skinning is then assessed visually as the percentage skinned surface (Dr A. Muir, personal communication).

Impact and bruising

Bruises may occur in different forms. The shatter bruise is externally visible but the blackspot bruise is invisible from the outside. The latter consists of internal cracking and crushing of tissue which results in discoloration of the internal tissue for potato (Skrobacki *et al.,* 1989; Kunkel and Gardner, 1959).

Several bruise testing methods have been developed by researchers and *dynamic methods* and *quasi-static methods* can be distinguished. The dynamic methods simulate the response of the actual tuber during impact, while quasi static methods produce information about the physical properties of the tubers (Skrobacki *et al.,* 1989).

Among the dynamic methods the susceptibility to bruising could, for example, be tested by dropping roots or tubers from a height (McGechan, 1981; Volbracht and Kuhnke, 1956). Other methods involve dropping a steel ball (Blight and Hamilton, 1974) or a metal plug within a guiding tube (Kunkel and Gardner, 1956) onto the root or tuber surface. Gall *et al.,* (1967) and Hughes *et al.,* (1975) used a pendulum under a rebound angle, for impact damage and found good correlations with damage at harvest and bruise volume. Other methods subjected roots or tubers to vibration on a riddle table (McGechan, 1980) or placing roots in a rotating drum (Dr A Muir, personal communication).

Among the static methods, some scientists found good correlations between puncture resistance and resistance to bruising using a penetrometer (Volbracht and Kuhnke, 1956;

Witz, 1954; Lampe, 1959). The penetrometer measures the force required to make a puncture. This can be done upon the outside surface and tissues at 2 mm deep. However, Blight and Hamilton (1974), did not consider this technique satisfactory to determine the susceptibility to overall mechanical damage.

5.2.3 Susceptibility to damage related to structural characteristics

Muir and Bowen (1994) found that the adhesion strength of the skin to the underlying parenchyma reduces the susceptibility to skinning injury. They found that as the adhesion strength increases, the other skin strength characteristics, such as resistance to tensile and shear forces, become more important as they may become the weakest components. When this occurs the type of damage is different and a more superficial skinning takes place, rather than large pieces of skin being removed.

Skin set can be induced by pre-harvest treatments. A common practice for potatoes is to destroy the haulm some time before harvesting. Skin-set occurs when the phellogen ceases to divide (Morris and Mann, 1955) and starts when the tubers are still in the ground (Bowen *et al.,* 1996; Muir and Bowen, 1994).

Webster *et al.,* (1973) reported that the soil temperature also affects susceptibility to damage and that roots harvested from warm and dry soils require higher peeling forces, indicating a higher resistance to damage, than roots harvested from colder soils.

5.3 Materials and Methods

The experiments on susceptibility to damage included the sweet potato roots from the trials 7, 8, 9, 10, 11b and 13.

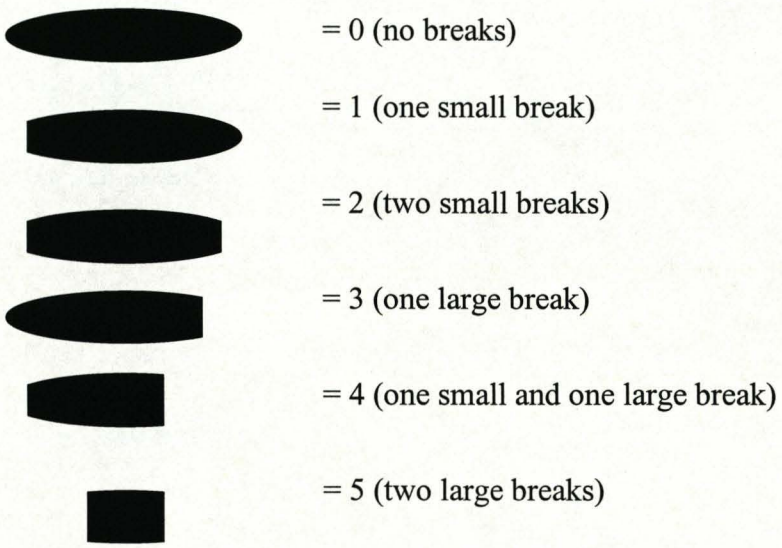
5.3.1 Assessment of damage

Susceptibility to damage was assessed during trial 7 and 10 after normal harvesting and in trial 8, 11b and 13 after artificial damage treatments. Measurements were made on individual sweet potato roots. Four types of damage were distinguished, i.e. breaks, deep wounds, superficial damage and skinning injury.

5.3.1.1 Breaks

In trial 11B and 13 breakage was assessed as the number of breaks per root, in which 0 refers to an unbroken root. In these trials the number of broken surfaces was counted. In trial 7 and 10 the number of breaks was scored according to a method described by Tomlins *et al.* (1999a) (Figure 5.1). In this system 0 = no breaks, 1= a small break, 2 = two small breaks, 3 = one large break, 4 = one small and one large break, 5 = two large breaks.

Figure 5.1 Scoring system for broken roots



Sourced from Tomlins et al. (1999)

5.3.1.2 Deep wounds

A deep wound was defined as a wound at least 5 mm deep (Plate 5.1a). The number of deep wounds per root were counted.

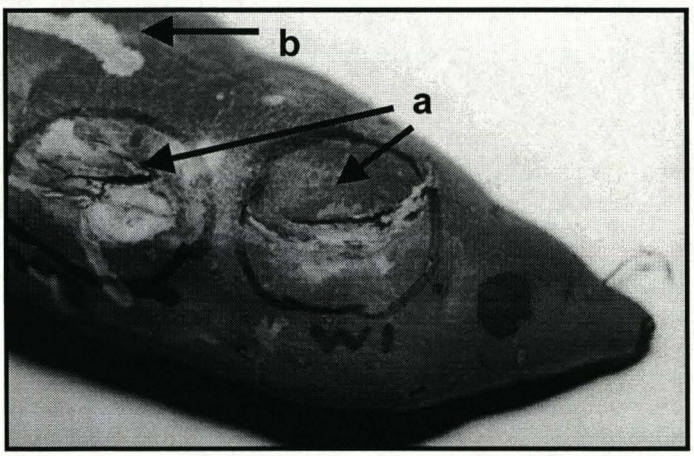


Plate 5.1 **Deep wounds (a) and scuffing (b) on sweet potato root surface (cultivar: KSP 20)**

5.3.1.3 Superficial damage

Superficial damage was defined as the abraded root surface up to a depth of 5 mm containing parenchyma as well as periderm, and was scored by visually estimating the percentage of the total abraded surface area.

5.3.1.4 Skinning injury

Scuffing was defined as an abrasion of the periderm and was scored by visually estimating the percentage of the total abraded surface area. (Plate 5.1b).

5.3.2 Standardised damage treatments

5.3.2.1 No treatment: impact of harvesting and transport.

In trial 7 and 10 no artificial damage treatment was applied. The roots were harvested by local women using hoes in trial 10, which is a standard tool. Sticks were used in trial 7 because the soil was wet. After harvesting, the roots were transported from the field to the laboratories by 4 wheel drive. Field replicates and cultivars were kept separate. The

remaining soil on the roots was carefully washed off using tap water. The roots were left to dry and then assessed.

5.3.2.2 Artificial damage treatments

Roots were harvested and stored for some days to equilibrate so that the weight loss was essentially constant before the damage treatment was applied. In trial 8 this equilibration time was 7 days, in trial 11B it was 2 days and in trial 13 it was 6 and 7 days. The two damage treatments were scuffing and impact.

Scuffing treatment

This method was adapted from a method developed by the Scottish Agricultural Research College. By rotating the barrel the roots inside are agitated simulating the agitation during handling and transport.

Ten sweet potatoes were placed in a metal barrel (length 0.55 m; diameter 0.38 m) with a rough internal surface. The barrel was then closed and rolled ten times on the floor at a rate of approximately 1 turn per 2 seconds. The amount of the surface abraded was recorded before and after the treatment for the individual roots. The score was expressed as percentage of the surface area. The rate of weight loss was monitored.

Impact treatment

This damage treatment was developed to simulate major impacts that occur during loading and off loading during transport and handling. Tomlins *et al.,* (1999a) found that sacks of sweet potatoes may be prone to 4 major impacts (> 10 g). According to their findings dropping from 1 m height is equivalent to an impact of approximately 30 g and the impact is not affected by the weight of the sack.

In the current research a polythene sack containing approximately 10 kg of roots was dropped four times from a height 1 m. The roots were assessed for damage as described in 5.3.1 before and after damage treatment. The rate of weight loss was recorded every two days for each individual root and in cases where roots were broken only the largest part was included.

5.3.3 Weight and water loss through damage

Weights of individual roots were recorded after damage at 1, 2, 7 and 14 days. A porometer (PP-Systems, Hitchin, UK) was used to measure the transpiration rate through damaged and undamaged surface. Six sweet potato roots, 2 for each of the cultivars KSP20, Kemb 10 and SPK 004 were chosen on the criterion that they had different kinds of damage such as deep wounds, scuffed surface area and superficial damage. The transpiration rate was measured as described in Chapter 4 section 3.3. For one root of KSP20 the transpiration rates were measured at 1, 3, 5, 7 and 14 days after harvest.

5.3.4 Pre-harvest pruning

Plants were pruned 1 week (trial 7) or 1 and 2 weeks (trial 10) prior to harvest. About 10 cm of the vines (Plate 5.2) was left in the ground. Replication of pruning was carried out as described below.

Plate 5.2 A pruned sweet potato plant about 0.2 m of the vines left in the ground

In trial 7 the cultivars were planted in rows containing 100 plants per cultivar. Each row was divided into 3 replicates as is shown in Figure 5.2 and 10 plants per replicate per cultivar were pruned.

		Rep 1		Rep 2		Rep 3	
		Unpruned	Pruned	Unpruned	Pruned	Unpruned	Pruned
Zapallo							
Yan Shu 1							
SPK004							
Kemb10							
KSP20							

Figure 5.2 Schematic outline of the plot in the field in trial 7.

In trial 10 the fields were replicated three times as a randomised complete block design. At 1 and 2 weeks before harvest, three plants per cultivar per replicate were pruned. Pruned plants were labelled with white or black strings so that the plants pruned 1 and 2 weeks before harvest could be distinguished. The roots of each replicate, cultivar and pruning harvest interval were transported to the laboratory separately in black dustbin liners. The roots were stored in crates as described in chapter 2 section 4.4, and weight loss was measured after 27 days.

5.3.5 Data analysis

Table 5.2 presents an overview of the trials and the damage treatments carried out.

Table 5.2 Overview of the trials and the experiments using damage treatment.

	7	8	9	10	11b	13
Mapping of water loss with porometer (M)	M		M			
Susceptibility to damage after normal harvesting (NH)	NH			NH		
Pruning effect on damage (P)	P			P		
Susceptibility to damage after treatments: Barrel (B) dropping (D)		B			B, D	B, D
Shape (Sh)					Sh	Sh
Periderm thickness (PT)			PT		PT	

Weight loss and damage

The relationship between weight loss and the amount of damage was determined by using the data collected of the individual roots. the correlation coefficients were obtained in Genstat and the significance of the correlations was determined using standard correlation coefficient tables (Naeve, 1978).

Susceptibility to damage

In the trials 7 and 10 blocking was carried out according to field replication and in trial 11b and 13 the artificial damage treatment was carried out in blocks. The means for the blocks on superficial damage, skinning injury, breakage and deep wounds, were analysed using analysis of variance (Table 5.3).

Table 5.3 Statistical design to test cultivar differences in susceptibility to damage.

	Factor	**Factor**	**Blocking structure**	
Trial	Cultivars	Pruning	Replicates	Number of roots per replicate
11b	9		6 × 2 days	2 to 3*
13	9		4	2 to 3*
7	5	0 and 1 week	3	7 to 11
10	5	0, 1 and 2 weeks	3	7 or 8

** This number was not available for some of the cultivars*

Structural aspects affecting susceptibility to damage

The association between shape and susceptibility to damage was carried out using contingency tables. In this method of analysis a matrix is formed with categories for shape in columns, and level of damage in the rows. The shapes, which were scored as described in Chapter 4, section 3.1.1, were regrouped into three categories. Category 1 comprised roots with round shapes including round, round elliptic and elliptic, category 2 comprised the ovate, obovate and oblong shaped roots, and category 3 comprised all the long shaped roots with a length:breadth ratio of 3:1. The damage scores were also categorised. Deep wounds were divided into 0 = no wounds, 1 = 1 deep wound, 2 = > 1 deep wound. For breakage the original scores were used, with 2 ≥ 2 breaks. The scores for skinning injury and superficial damage were categorised in 4 categories into low, intermediate-low, intermediate-high and high, using normal distribution patterns in

Genstat. The significance of the association between the rows (damage) and columns (shapes) of the contingency tables were assessed using the Pearson Chi square values, in which the P value gives the probability that this distribution occurs by chance.

The relationship between periderm thickness and susceptibility to damage was carried out using regression analysis. The mean values for periderm thickness as presented in chapter 5 were used.

5.4 Results and discussion

5.4.1 Damage and storability

5.4.1.1 Increase in weight loss caused by damage

Two artificial damage treatments were applied to sweet potato roots. These comprised a scuffing treatment, suing a scuffing barrel, and impact treatment that was inflicted by dropping a bag of roots on the ground from a height of 1 m. Damage was scored visually. (The data on damage are presented in Figure 5.4 and 5.5, and discussed later in section 4.2). The correlation coefficients between weight loss and damage were determined using the data of individual roots for the amount of damage and the rate of weight loss. Table 5.4 presents the correlation coefficients obtained, irrespective of the cultivar.

Table 5.4 Correlation coefficients for the amount damage and the rate of weight loss measured at 1, 2, 7 and 14 days after the damage treatment.

Treatment	Trial	Number of roots	Damage	Rates of weight loss at day 1	day 2	day 7	Day 14
Scuffing Barrel	Trial 8	N = 100	Skinning injury	0.348**	0.449**	0.050	
	Trial 11B	N = 72	Skinning injury	-0.145	-0.095	-0.383**	-0.435**
	Trial 13	N= 230	Skinning injury	0.535**	0.426**	0.087	
Impact Damage	Trial 13	N = 217	Broken parts	0.479**	0.435**	0.547**	
			Broken surfaces	0.480**	0.414**	0.541**	
			Skinning injury	0.253**	0.155*	0.053	
			Deep wounds	0.089	0.140*	0.274**	
			Superficial damage	0.166*	0.095	-0.008	
Impact Damage	Trial 11B	N = 72	Broken parts	0.504**	0.572**	0.701**	0.640**
			Broken surfaces	0.549**	0.588**	0.712**	0.669**
			Skinning injury	0.087	0.252*	0.172	0.046
			Deep wounds	-0.035	-0.185	-0.098	-0.128
			Superficial damage	0.146	0.129	0.070	0.101

*** Significant at P < 0.001*

** Significant at P < 0.05*

The correlation between skinning injury after scuffing treatment in the scuffing barrel, and the rate of weight loss were highly significant for trial 8 and 13. This is in correspondence with findings by Stikeleather and Harrell (1990). During storage time the correlation coefficient decreased, indicating that skinning injury plays a lower role in the rate of weight loss after 1 week. The negative correlation found during trial 11B was not

understood. It could be that the equilibration time between harvest and damage treatment was too short (2 days), and that the damage that had occurred during harvesting and transport from the field to the laboratories affected the weight loss more than the scuffing after the treatment.

The rate of weight loss after impact damage correlated positively with breakage. This correlation remained highly significant until 14 days after damage treatment. Skinning injury and superficial damage were correlated to the rate of weight loss in trial 13, but the correlation coefficients decreased during storage. This could be due to the healing process of the damaged areas.

These findings suggest that the sort of damage can have a long term effect on weight loss (breakage) or a short time effect (skinning injury and superficial damage). It is likely that this is related to the rate of wound healing.

5.4.1.2 Increase in transpiration rate caused by damage

The transpiration rate through the damaged areas was higher than the transpiration rate through the undamaged areas. This is illustrated in Table 5.5 that presents the transpiration rate upon different kinds of damage measured with a porometer. The damage was not artificially inflicted but consisted of the 'natural damage' due to harvesting and handling.

The transpiration rate through damaged areas was often more than ten times as high as the transpiration rate through undamaged periderm. The transpiration rates of undamaged periderm were between 1 and 16 $mmol \cdot m^{-2} \cdot s^{-1}$. For undamaged periderm containing lenticels it was slightly higher, between 6 and 15 $mmol \cdot m^{-2} \cdot s^{-1}$ and on areas where fibrous came out the transpiration rate was between 12 and 22 $mmol \cdot m^{-2} \cdot s^{-1}$. The highest transpiration rate, 233 $mmol \cdot m^{-2} \cdot s^{-1}$ was measured through areas with skinning injury while deep wounds gave an average transpiration rate of 142 $mmol \cdot m^{-2} \cdot s^{-1}$. Broken surfaces had an average transpiration rate of 76 $mmol \cdot m^{-2} \cdot s^{-1}$, and superficial damage had a mean value of 56 $mmol \cdot m^{-2} \cdot s^{-1}$.

Table 5.5 Transpiration rate ($mmol \cdot m^{-2} \cdot s^{-1}$) of root surface of individual roots upon areas with and without damage measured with a porometer at 1 day after harvest.

wound	Kemb10 A	Kemb10 B	KSP20 A	KSP20 B	SPK004 A	SPK004 B	Mean values
Skinning injury + superficial			233.2				233.2
Skinning injury			226.3				226.3
Deep wound	182.8					122	142.3
Broken surface	84.4	82.4				53.2	75.6
Sprout	63						63.0
Superficial damage		55.9	69.7	26.3	67.1		56.1
Top of root				56			56.0
Undamaged periderm + fibrous root	12.4					21.8	17.1
Undamaged periderm + lenticel	15.2	5.8	18.2		17.7		15.4
Undamaged periderm	13.1	6	15.6	2	13.0	3.8	7.8

Figure 5.3 presents the development of the transpiration rate through damaged and undamaged areas during storage. The transpiration rate was highest at day 1 for all types of root surface. It then dropped steeply, reaching a lowest value at day 7 which was approximately 30% of the rate at day 1. On day 14 the measured transpiration rates were generally higher than on day 7. It is not clear why this was the case. Deep wounds showed the highest transpiration rates, followed by areas with superficial and skinning injury. The transpiration rate through irregular areas such as nodes for fibrous roots was only a little higher than the undamaged periderm.

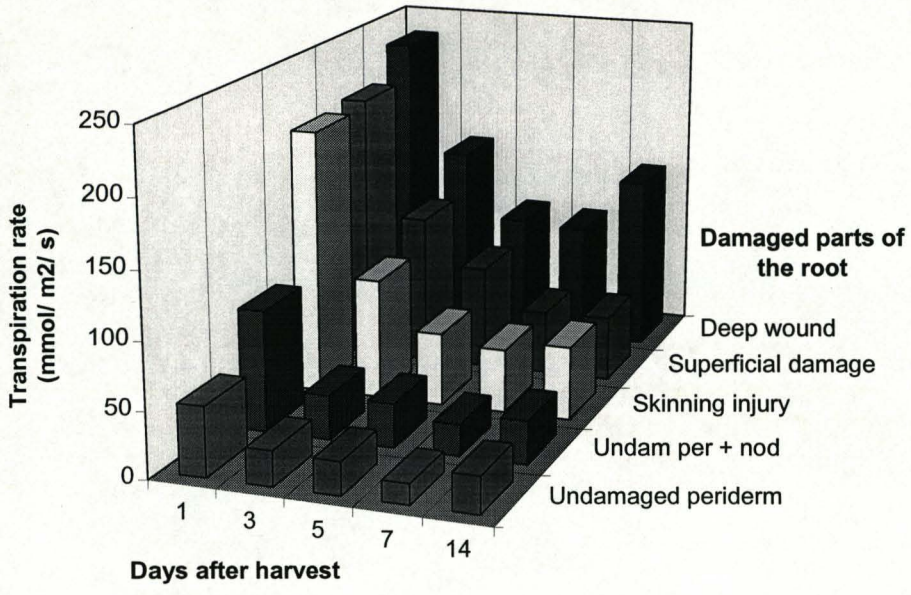


Figure 5.3 Transpiration rate through root surface with different kinds of damage measured at 1, 3, 5, 7 and 14 days after harvest. Cultivar: KSP 20. (Note that the scale is not linear).

The decrease in transpiration through undamaged periderm was in agreement the findings of Lulai and Orr (1994) who described a similar pattern during skin-set of potato. The decrease in transpiration through damaged surface is probably a result of wound healing but after 7 and 14 days it was still higher than undamaged periderm suggesting that if a wound periderm is formed, it is not as efficient as the native periderm. Deep wounds kept a higher transpiration rate than skinning injury and superficial damage.

5.4.2 Cultivars and susceptibility to damage

5.4.2.1 Scuffing treatment

Figure 5.4 presents the effect of scuffing treatment on the susceptibility to skinning injury of different sweet potato cultivars. In all trials the cultivar effect was significant upon susceptibility to skinning injury ($P < 0.001$). The highest susceptibility for skinning injury was found for the cultivars Zapallo and Julian in trial 13 with a percentage of skinning between 11 and 25%. During trial 11 the highest amounts were observed for BP1-SP-2, KSP 20 and Salyboro. The cultivars SPK 004 and Kemb10 were consistently low in susceptibility to skinning injury.

During preliminary trials at the Scottish Agricultural College, a comparison was made between potato and sweet potato for the susceptibility to scuffing using a scuffometer and thumb tests. No data were collected, but it was observed that sweet potato was less susceptible to skinning injury than potato. Sweet potato periderm had a lower tensile strength in relation to its the adhesion strength which made it difficult to separate the periderm from the parenchyma. The tensile strength was also lower than in potato. (Dr A. Muir, personal communication).

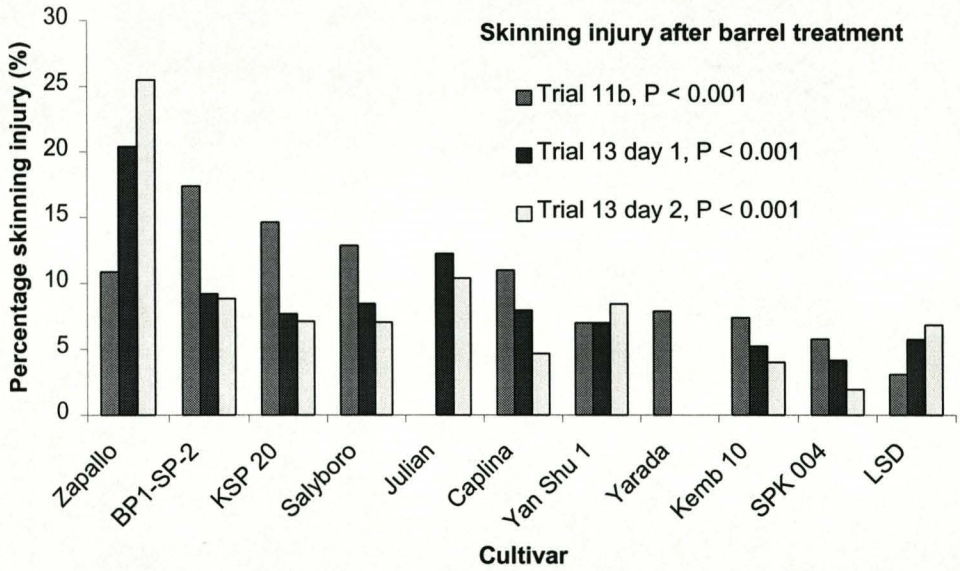


Figure 5.4 Susceptibility to skinning injury after artificial scuffing in a barrel for 10 sweet potato cultivars from trial 11B and trial 13 on day 1 and 2. The percentage of root surface area with skinning injury was visually estimated.

5.4.2.2 Impact treatment

Figure 5.5 a to d presents the effect of dropping sweet potato roots (four times) from a height of 1 m on skinning injury, superficial damage, breakage and deep wounds. The most susceptible cultivar for skinning injury was Zapallo and the least susceptible was SPK 004. This corresponds with the findings concerning skinning injury after treatment in the scuffing barrel. There were no significant cultivar differences in the susceptibility to superficial damage during trial 11B and trial 13 day 2. During trial 13 day 1 there were

significant differences among the cultivars ($P < 0.001$) and Kemb 10 and SPK 004 were most susceptible to superficial damage.

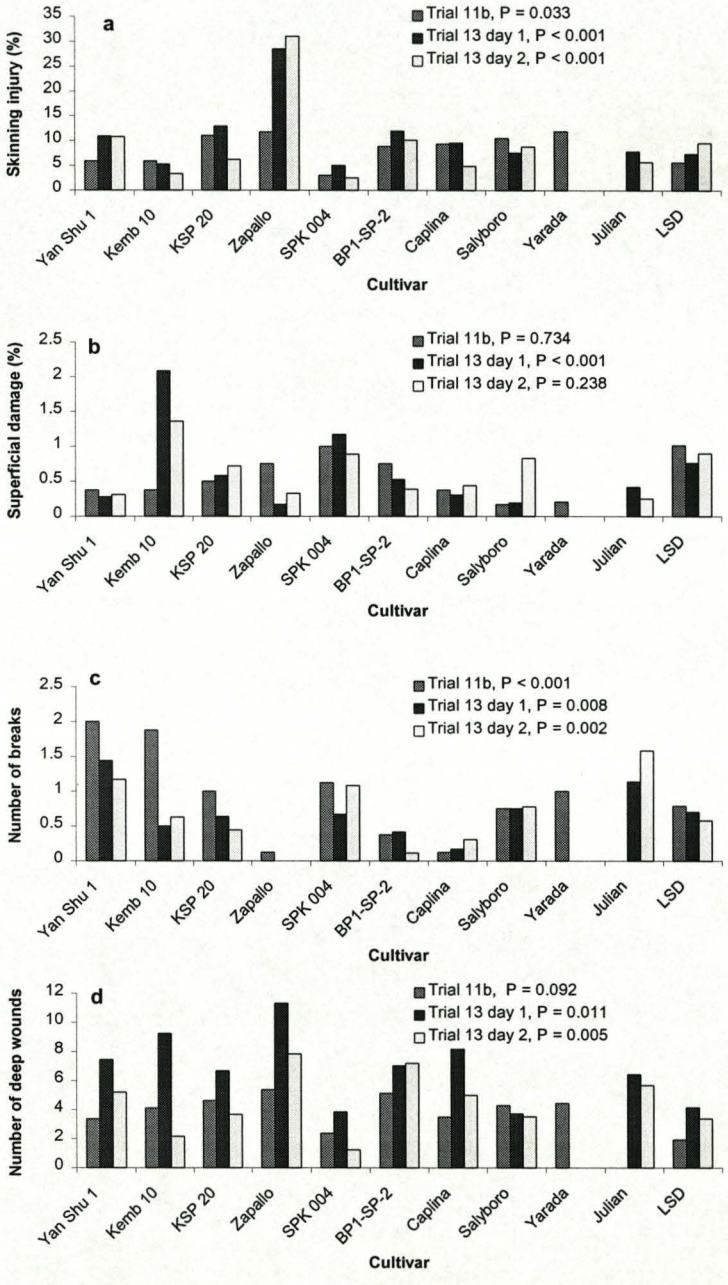


Figure 5.5 Susceptibility to damage for 10 sweet potato cultivars after dropping the roots 4 times from 1 meter during trial 11B and 13. Each value is the mean of 6 replicates. LSD = Least Significant Differemce.

The cultivars differed significantly in their susceptibility to breakage. The most susceptible cultivars for breakage were Yan Shu 1, Kemb 10 and SPK 004 with a mean number of breaks > 1 while the occurrence of breakage in Zapallo, BP1-SP-2, and Caplina was low and close to zero. For the occurrence of deep wounds it was observed that SPK 004 had a consistently low score while Zapallo had a consistent high score. Significant cultivar differences were only observed in trial 13

5.4.2.3 Ranking of cultivars

In order to make overall comparisons the cultivars were ranked according to their susceptibility to damage. Table 5.6 presents an overview of the ranks of the means for each of the damage treatments.

Table 5.6 Overview of ranks for susceptibility to damage for 10 sweet potato cultivars. A high rank corresponds with a high susceptibility to the particular form of damage, and corresponds with a dark grey in the mean scores.

Treatment	Trial	Damage	Cultivars									
			Yan Shu 1	Kemb 10	KSP 20	Zapallo	SPK 004	BP1-SP-2	Caplina	Saly-boro	Yarada	Julian
Scuffing												
Barrrel	11b	Skinning	2	3	8	5	1	9	6	7	4	
	13	Skinning	5	2	4	9	1	7	3	6		8
Mean rank		**Skinning**	**3.5**	**2.5**	**6.0**	**7.0**	**1.0**	**8.0**	**4.5**	**6.5**	**4.0**	**8.0**
Impact												
Damage	11b	Breaks	9	8	5	1	7	3	2	4	6	
	13	Breaks	9	6	5	1	8	3	2	7		4
	11b	Deep	3	5	6	8	9	7	4	2	1	
	13	Deep	3	9	7	1	8	5	4	6		2
	11b	Skinning	2	3	8	6	1	9	5	7	4	
	13	Skinning	7	2	5	9	1	8	3	4		6
	11b	Superf	2	5	7	9	1	8	3	6	4	
	13	Superf	5	6	3	9	1	8	7	2		4
Mean rank		**Breaks**	**9.0**	**7.0**	**5.0**	**1.0**	**7.5**	**3.0**	**2.0**	**5.5**	**6.0**	**4.0**
		Deep	**3.0**	**7.0**	**6.5**	**4.5**	**8.5**	**6.0**	**4.0**	**4.0**	**1.0**	**2.0**
		Skinning	**4.5**	**2.5**	**6.5**	**7.5**	**1.0**	**8.5**	**4.0**	**5.5**	**4.0**	**6.0**
		Superf	**3.5**	**5.5**	**5.0**	**9.0**	**1.0**	**8.0**	**5.0**	**4.0**	**4.0**	**4.0**

The profiles of susceptibility to damage differ among the cultivars. Upon damage treatment in the scuffing barrel BP1-SP-2, Julian and Zapallo scored high, while SPK 004 and Kemb 10 scored low.

Upon impact SPK 004 was consistently susceptible to breaks and deep splits and cracks, but had the lowest susceptibility to skinning injury and superficial damage. A similar pattern was found for Kemb 10. Yan Shu 1 was highly susceptible to breaks but not susceptible to deep wounds. Zapallo and Caplina were least susceptible to breakage and Yarada and Julian were least susceptible to deep wounds. Zapallo and BP1-SP-2 were highly susceptible to skinning injury and superficial damage. KSP 20 and Salyboro ranked intermediate for all forms of damage. It was noted that the ranking of susceptibility to skinning injury was consistent for both the barrel treatment and impact damage.

5.4.3 Root shape and susceptibility to damage

5.4.3.1 Scuffing treatment

The association between shape and skinning injury was assessed using the data of individual roots, independent of cultivar. A contingency table with categories for shape and the skinning injury, is presented in Table 5.7 and contains the numbers of roots in each category. For shape three categories were used.

Table 5.7 Contingency table presenting the number of roots per category of shape and skinning injury after scuffing treatment. The shape categories refer to the shapes in Chapter 4, Table 4.3.

Trial 11b	Number of roots			Trial 13	Number of roots		
Skinning Score (%)	Shape categories			Skinning Score (%)	Shape categories		
	1 to 3 round	4 to 6	7 to 9 long		1 to 3 round	4 to 6	7 to 9 long
< 7	3	1	11	< 3	17	13	14
< 9	4	4	6	< 7	21	18	26
< 14	3	12	7	< 11	9	22	27
> 14	4	10	6	> 11	12	16	36
Association between shape and skinning injury after rolling roots in a barrel. Pearson Chi square value: 12.22 With 6 df, P = 0.057				**Association between shape and skinning injury after rolling roots in a barrel. Pearson Chi square value: 13.35 With 6 df, P = 0.038**			

The effect of shape on susceptibility to skinning injury was not consistent. Although the significance of trial 13 indicated some association ($P = 0.038$) there was no clear pattern. In trial 11B, there was a trend that long shaped roots had a lower susceptibility to skinning injury and roots of intermediate length were more susceptible. Only a low number of roots had a round shape (14 roots) and no association with skinning injury was observed for these roots.

5.4.3.2 Impact treatment

Table 5.8 presents the contingency tables for susceptibility to damage after impact treatment (4 x dropping from 1 m height). The only form of damage that was consistently associated with shape was the occurrence of breaks (in both trial 11b and 13, $P < 0.001$). Breakage was associated with a longer shape of root (length:breath ratio: 3:1), while less incidences of breakage occurred for round shapes.

For other sorts of damage some association was observed. In trial 11b the shape was significantly associated with occurrence of deep wounds, and relatively more deep wounds occurred for round shapes than long shapes, but this was not consistent for trial 13. The occurrence of superficial damage was significantly associated with shape in trial 13 although no clear pattern was observed, and no association at all was observed in trial 11B. No association was found between skinning injury and shape.

Table 5.8 Contingency table presenting the number of roots per category of shape and skinning injury after impact treatment by dropping four times from a height of 1 m. The shape categories refer to the shapes in Chapter 4, Table 4.3.

Trial 11b				Trial 13			
Breaks Score	Shape 1 to 3	4 to 6	7 to 9	Breaks Score	Shape 1 to 3	4 to 6	7 to 9
0	12	13	6	0	35	50	46
1	5	1	14	1	11	15	33
>2	1	1	19	>2	3	2	23
Association significant Pearson Chi square value: 30.38 with 4 df, P < 0.001				**Association significant Pearson Chi square value: 23.47 with 4 df, P < 0.001**			
Trial 11b				**Trial 13**			
Deep wounds Score	Shape 1 to 3	4 to 6	7 to 9	Deep wounds Score	Shape 1 to 3	4 to 6	7 to 9
0	7	13	28	0	35	43	70
> 1	11	2	11	1	5	19	18
				>2	9	10	17
Association significant Pearson Chi square value: 9.41 with 2 df, P = 0.009				**Association insignificant Pearson Chi square value: 5.36 with 4 df, P = 0.253**			
Trial 11b				**Trial 13**			
Skinning Injury (%)	Shape 1 to 3	4 to 6	7 to 9	Skinning Injury (%)	Shape 1 to 3	4 to 6	7 to 9
< 2.5	4	2	11	< 3	18	14	21
< 4	5	5	7	< 6	11	17	24
< 5	3	5	10	< 12	8	17	34
> 5	6	3	11	> 12	12	24	26
Association insignificant: Pearson Chi square value: 3.75 with 6 df, P = 0.711				**Association insignificant Pearson Chi square value: 9.62 With 6 df, P = 0.141**			
Trial 11b				**Trial 13**			
Superficial damage (%)	Shape 1 to 3	4 to 6	7 to 9	superficial Damage (%)	Shape 1 to 3	4 to 6	7 to 9
< 5	4	3	11	< 2	9	10	22
< 8	2	4	7	< 5	21	13	34
< 12	4	4	7	< 9	8	28	22
> 12	8	4	14	> 9	11	21	27
Association insignificant: Pearson Chi square value: 2.60 with 6 df, P = 0.857				**Association significant Pearson Chi square value: 15.47 With 6 df, P = 0.017**			

5.4.4 Periderm thickness and susceptibility to damage

Figure 5.6 presents the relationship between the periderm thickness (in μm and cell layers) of 10 cultivars in relation to percentage skinning injury induced by the scuffing barrel. A clear trend was observed indicating that the susceptibility to skinning injury decreased as the periderm gets thicker. This relationship was found to be significant for the periderm thickness expressed in μm ($P = 0.037$).

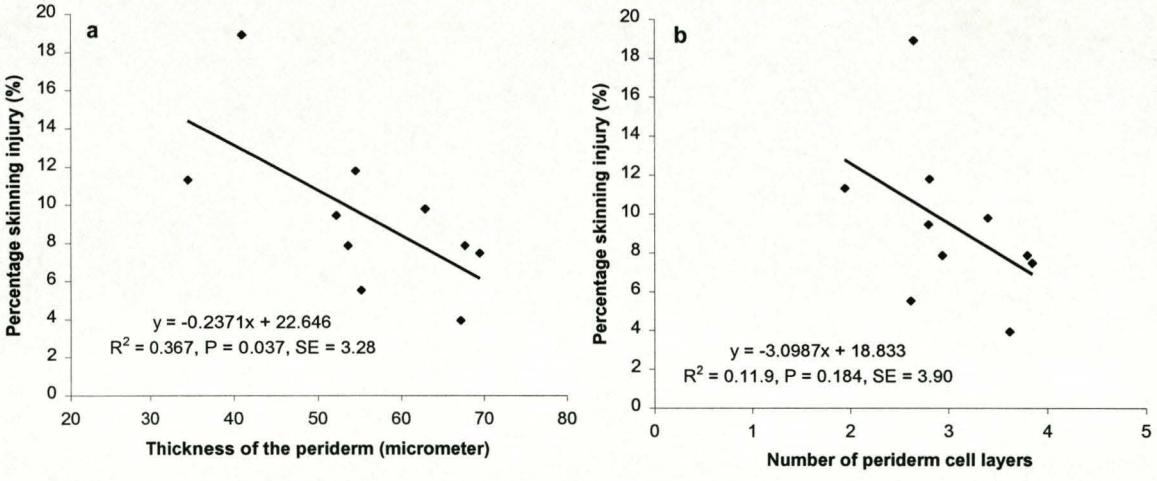


Figure 5.6 Relationship between periderm thickness, number of periderm layers and percentage to skinning injury (percentage surface area of the root) after scuffing treatment. Each point represents a cultivar. Periderm data were obtained from trials 9 and 11, and the skinning injury data are the means of trials 11b and 13.

5.4.5 The effect of pruning on susceptibility to damage

The effect of pruning on occurrence of damage after normal harvesting was assessed during trial 7 and 10. Table 5.9 presents the results of the damage observed and gives cultivar effects as well as the effects of pruning treatment.

Table 5.9 Effect of pruning on susceptibility to different categories of damage after normal harvesting, transport and handling for 5 sweet potato cultivars. Each value is the mean of 3 replicates, consisting of 7-11 roots each.

Time of pruning before harvest		Cultivar					Cultivar effects	Pruning Effects
Trial 7	**Wks**	**Yan Shu 1**	**Kemb 10**	**KSP 20**	**Zapallo**	**SPK 004**	**P value** *LSD*	**P value** *LSD*
Breaks [1]	0	0.22	1.02	0.05	0.06	0.38	**0.002**	**0.035**
	1	0.08	0.27	0.08	0.09	0.23	***0.284***	***0.179***
Deep wounds [2]	0	0.58	0.79	0.78	0.41	0.94	**0.475**	**0.393**
	1	0.53	0.67	0.69	0.41	0.58	***0.47***	***0.297***
Skinning [3]	0	1.07	1.12	2.11	1.61	1.26	**0.132**	**0.248**
	1	1.50	0.61	1.87	0.97	0.51	***0.950***	***0.601***
Superficial Damage [3]	0	2.07	2.64	2.20	2.40	3.07	**0.771**	**0.130**
	1	1.40	1.41	2.35	1.98	2.04	***1.337***	***0.846***
Weight loss after 27 days storage	0	9.17	12.67	9.80	14.37	18.15	**0.001**	**0.030**
	1	9.60	10.68	7.67	10.70	14.13	***3.214***	***2.032***
Trial 10								
Breaks [1]	0	0.08	0.63	0.31	0.13	0.71	**< 0.001**	**0.378**
	1	0.17	1.21	0.13	0.17	1.10	***0.419***	***0.325***
	2	0.42	1.00	0.42	0.04	1.00		
Deep wounds [2]	0	0.17	0.04	0.18	0.13	0.33	**0.476**	**0.946**
	1	0.00	0.33	0.21	0.17	0.25	***0.183***	***0.141***
	2	0.13	0.21	0.25	0.13	0.17		
Skinning [3]	0	2.50	2.17	10.51	3.75	1.92	**< 0.001**	**< 0.001**
	1	1.08	0.75	6.29	1.36	0.26	***1.38***	***1.07***
	2	0.71	0.33	2.79	0.42	0.25		
Superficial Damage [3]	0	3.17	5.96	4.49	5.38	6.83	**0.005**	**0.015**
	1	2.88	3.83	4.29	5.75	4.52	***1.15***	***0.89***
	2	2.92	4.42	4.34	3.21	4.29		
Weight loss after 27 days storage	0	9.58	20.77	14.61	15.41	23.02	**< 0.001**	**0.478**
	1	9.50	23.26	11.59	20.16	24.14	***3.361***	***2.604***
	2	10.01	20.95	10.54	14.90	24.60		

1) Breaks according to the scoring system by Tomlins et al., (1999a)
2) Mean of number per root
3) Percentage of the surface area

It was noted that during trial 10 the amount of damage was higher than in trial 7. The total of skinning injury and superficial damage was between 2.02 and 4.33% in trial 7 while in trial 10 the amount of damage varied between 3.63 and 15%.

Significant differences among the cultivars were observed for the occurrence of breaks in both trials. The cultivars Kemb 10 and SPK 004 had relatively more breaks than the other cultivars. This is in correspondence with earlier findings in section 4.2.2. Only in trial 7 pruning had a significant effect on occurrence of breakage.

In both trials the cultivar KSP 20 was most susceptible to skinning injury. This is surprising since KSP 20 had intermediate scores after artificial damage. This difference could be related to the fact that the damage treatments were carried out at six and five days after harvesting, and it is possible that the skin-set had been completed during this time in the same way as it does for potatoes (Bowen *et al.*, 1996).

In trial 10 pruning had a beneficial effect on skinning injury of KSP 20, which was reduced from 10.51% to 2.79%. This decrease coincided with the reduction in weight loss from 14.61% to 10.54%. This is in agreement with finding in the literature on skinning injury in sweet potato (Stikeleather and Harrell, 1990) who reported that the weight loss of sweet potatoes was reduced from 5% to 3.5% when the vines were removed prior to harvesting.

In trial 7, however no cultivar difference was observed for skinning injury. Nor was skinning injury affected by pruning, but this could be explained by the fact that the scores for skinning injury were very low in trial 7. This was possibly related to the extra care that had been taken during harvesting. Future assessments should include a standardised damage treatment to effectively assess the impact.

In trial 10 the superficial damage was significantly reduced by pruning the plants before harvest. In trial 7 reductions were observed as well, but there was no significance. Yan Shu 1 was least susceptible to superficial damage.

5.5 Summary and conclusions

5.5.1 Summary of findings

- Water loss through damaged areas is many times higher than through undamaged periderm
- Breakage has the highest effect on the rate of weight loss and correlated with weight loss for up to 14 days.
- Skinning injury and superficial damage correlated with weight loss during the first days after damage, but became less significant after 1 week. This is probably due to wound healing.
- Sweet potato cultivars differ in susceptibility to damage and also in the kind of damage they are susceptible for. SPK 004 and Kemb 10 are susceptible to breaks, while Zapallo, BP1-SP-2 and Julian are susceptible to skinning injury. The least susceptible cultivars were Caplina and KSP 20.
- The shape of the root affects the susceptibility to breakage of roots, but other sorts of damage were more affected by the cultivar than by shape alone.
- The susceptibility to skinning injury for a cultivar was negatively correlated to the periderm thickness.
- Pre-harvest pruning does not effectively reduce damage or weight loss. Only for the cultivar KSP 20 pruning had beneficial effects by reducing skinning injury and, as a result, the weight loss.

5.5.2 Conclusions

- Damage increases the rate of water loss and is therefore an important factor for storability under tropical conditions.
- The form of damage that has the most severe impact on weight loss is breakage
- Cultivars do differ in their susceptibility to damage

Chapter 6

Wound healing

6.1 Introduction

In Chapter 5 it was established that damage is an important factor for water loss and that sweet potato cultivars differ in their susceptibility to damage. However, susceptibility to damage did not account for all cultivar differences in water loss. With respect to storability it is now important to look at how the sweet potato cultivars deal with the damage, and whether differences in wound healing exist among cultivars.

In the US it is common practice to cure sweet potatoes before storage. The conditions recommended are a relative humidity of at least 85% and a temperature between 25 and 33°C. In tropical areas curing is not part of the standard post harvest process. However it is believed that the roots may cure naturally due to the prevalent high temperatures and relative humidity (Woolfe, 1992). Evidence that this is the case was reported by Jenkins (1982) who found that artificial curing under tropical conditions in Bangladesh did not give any reduction in weight loss. However, the relative humidity in the tropics might be too low for curing to take place.

The effect of these conditions on the wound healing process has been given little consideration so far. This chapter first stidies the physiological processes that occur in wounded roots when kept under sub-optimal conditions. A rapid method to assess wound healing efficiency of sweet potato cultivars was then developed and the relationship between wound healing and aspects of storability of the cultivars was investigated.

6.2 Literature review

Most plants have mechanisms that protect the wound site and help the organism or organ to recover from damage. For sweet potatoes the process of protection is the formation of a wound periderm and is similar to potato, cassava and yam. The initial protective mechanism often involves the synthesis of antimicrobial phenolics. Then a new periderm like layer is formed under the exposed tissue: the wound periderm.

6.2.1 Physiology of wound healing

Descriptions of the process of wound healing in sweet potatoes date from as early as 1921, when Weimer and Harter investigated the conditions under which wound healing occurs. Artschwager and Starret (1931) distinguished the three stages involved; 1) The desiccation of several cell layers of parenchyma; 2) The thickening of cell walls (suberization or lignification); 3) The formation of wound periderm.

6.2.1.1 Desiccation

Desiccation of cell layers is the first response after wounding. The cells on the surface dry out and die. When the healing is rapid this layer is thin and between 4 to 6 layers, but when the healing process is slow, for example if curing conditions are sub-optimal, the number of desiccated cell layers is higher and 17 layers have been measured (Strider and McCombs, 1958). The wound surface becomes hard, dark, and sunken which renders the wounds conspicuous and unattractive and a wound periderm is seldom formed underneath (Morris and Mann, 1955; Weimer and Harter, 1921; Artschwager and Starret, 1931). Thick desiccated cell layers can favour the growth of pathogens on wounds (Nielsen and Johnson, 1974). Also the age of the roots may affect the thickness of the desiccated cell layers (Strider and McCombs, 1958).

6.2.1.2 Lignification

In the second phase, the cell walls below the desiccated layer start to thicken. This is often referred to as suberisation (Artschwager and Starret, 1931). Suberisation is defined as the deposition of suberin in or on the inner surface of the cell walls. Kolattukudy (1984) developed a tentative model of the ligno-suberin matrix based on biochemical and morphological evidence. A schematic diagram of this model is shown in Figure 6.1. The model places hydrophobic (lipid) and lignin-like (phenolic) components in a layered matrix.

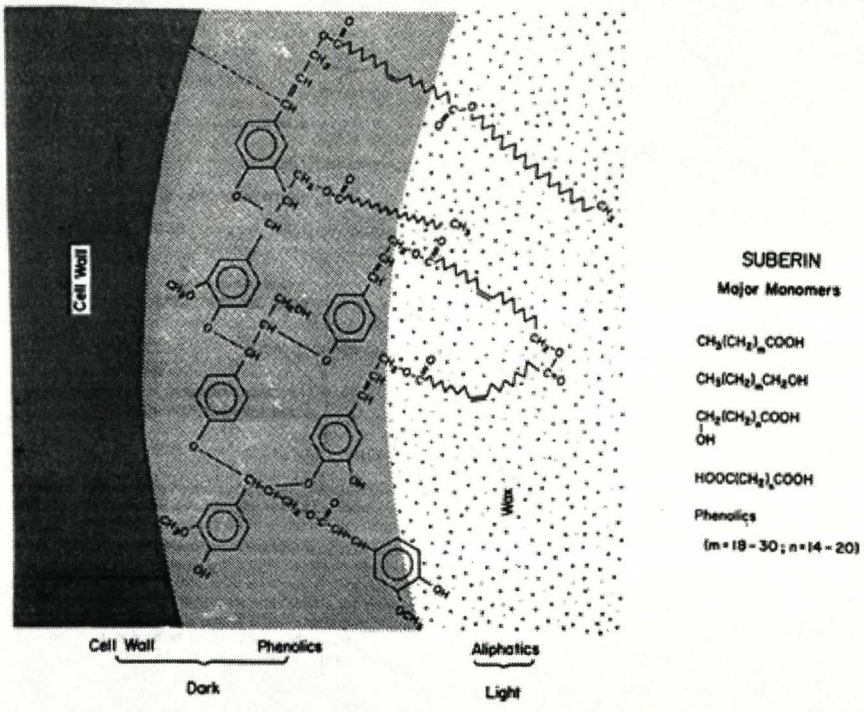


Figure 6.1 A schematic representation of suberised cell wall indicating the postulated features.
(Sourced from Kolattukudy, 1984)

Suberin is considered to be a waxy material and the usual stain to indicate the presence of suberised cell walls is Sudan IV, a fat soluble dye (McClure, 1960). The polymeric materials appear to be primarily responsible for protection of wounds against pathogens. It appears that pathogens are unable to effectively degrade mature suberin (Kollatukudy and Soliday, 1985; Kolattukudy, 1984), at the same time the associated suberin type waxes prevent desiccation (Schönherr, 1976; Soliday *et al.*, 1979, Vogt *et al.*, 1983, Dean 1989). Riley and Kolattukudy (1975) found that suberin in sweet potato contained ferulic acids, and that ferulic acid is probably covalently attached to suberin.

Artschwager and Starret (1931) found that the lignified layer in sweet potatoes absorbs crystal violet which indicates suberisation. Later, McClure (1960) found that those cells had a much stronger affinity for a saturated solution of phloroglucinol in 18% HCl, which indicated a lignin like structure. Walter and Schadel (1983) used mass spectrometry to confirm that the polymeric compound had the chemical properties of lignin.

The thickness of the lignified layer is used by several scientists as a measure for progress of the wound healing process. Cultivars might differ in the thickness of the lignified layers, but generally four to five lignified layers need to be formed before the wound periderm develops underneath. The intensity of the colour developed with phloroglucinol/HCl relates to its thickness. Lignification is probably the most crucial step in the wound healing process. After lignification a wound periderm is formed underneath, even if the roots are removed from curing conditions (Walter and Schadel, 1982; 1983).

6.2.1.3 Wound periderm formation

The wound periderm is also called cork (Morris and Mann, 1955) or wound phellem (Strider and McCombs, 1958). With the formation of this new protective layer, the process of wound healing is complete. The wound periderm consists of layers of cells, stacked in a similar way as the native periderm and resembles the natural periderm except that it is formed after harvest. The thickness of the wound periderm may vary according to the cultivar. Morris and Mann (1955) found thicknesses varying from 4 layers to 10 layers while Walter and Schadel, (1983) and St Amand and Randle, (1991) found thickness between 5 and 6.7 layers. Generally a wound periderm of about 4.2 layers is necessary for protection. It can develop under both curing and cooler conditions, but under curing conditions it develops quicker (Walter and Schadel, 1982).

6.2.2 Factors affecting the wound healing efficiency

6.2.2.1 Environmental conditions

Weimer and Harter (1921) determined that the temperature and humidity are important factors in wound healing of sweet potato. Wound healing takes place at at temperatures

varying from 19.5°C to 33°C, but the optimum temperature was 33°C. A relative humidity of > 95% is most favourable. At lower relative humidity more cell layers desiccate at the surface.

6.2.2.2 Type of wound

Some scientists have reported that depth of the wound affects the healing process. In potato deeper tangential wounds (3.0 mm) had slower initial rates of wound healing than did shallow wounds (0.75 mm) (Lulai and Orr, 1995). Strider and McCombs (1958) found that the wound healing process in sweet potato occurred at the same rate in 2 mm deep wounds as in 8 mm deep wounds. For yams it was found that scuffing injury and less deep wounds healed more slowly than deeper cut wounds (Passam *et al.,* 1976a). For cassava it was found that wound of 2 mm depth healed more easily than wounds of 8-10 mm depth (Akhimienho, 1999).

The rate of wound healing also seems to be affected by the location of the wound and Weimer and Harter (1931) found that wound periderm was produced more readily near to the vascular ring compared to the centre. Wounds on the side of the roots were reported to heal more rapidly than wounds on the ends of the roots.

Bruise-type wounds heal slower than cut wounds and the cork formation is slow and irregular (Strider and McCombs, 1958;). At the inner depths of these wounds, at approximately 30 to 50 cells below the surface, wound phellogen was seldom found. Pressure bruised areas were found to cause an elevated water vapour loss, which continued to increase even at four days after removal from the pressure bruising environment (Lulai *et al.*, 1996). Possibly the lack of oxygen (Weimer and Harter, 1931) or decreased transpiration may be factors which limit wound periderm formation deep in the root under bruise-type wounds (Strider and McCombs, 1958).

6.2.2.3 Other factors

The maturity affects the rate of wound healing: mature potato heal wounds more rapidly (Lulai and Orr, 1995). The lignification rate is affected by the soil temperature from which the roots are harvested, and is higher for 22-25°C than for 10-12°C or 15-17°C. The rate of lignification, however, did not relate to the storability (Walter *et al.,* 1989).

6.2.3 Measuring wound healing

Wound healing can be measured in several ways. Popular methods include counting the number of lignified layers, counting the number of wound periderm layers and measurements of transpiration through wound surface. These methods are summarised below.

6.2.3.1 The number of lignified cell layers

The colour intensity of the stained lignified layer is a measure to assess the process of lignification. It was found that 1.4 layers of lignified cells stained pink, 2.6 layers stained red, and above 4 layers stained reddish-purple (Walter and Schadel, 1982)

6.2.3.2 Wound periderm formation

Strider and McCombs (1958) counted the number of wound phellem layers. They found that wound phellem started after 3 days at 29°C, 95% RH. A disadvantage of measuring the wound periderm layer is that it is time consuming, and that it can only be carried out at more than 8 days after wounding.

6.2.3.3 Wound healing efficiency: water loss

Lulai and Orr (1995) measured the wound healing efficiency of potato by determining the transpiration rate through the wounds using a porometer. This method was accurate enough to detect variability in relation to the maturity and cultivar. The transpiration rate of wounds in potato tubers declines in a log-linear fashion during the first 3 days, with the steepest drop during the first 24 hours.

6.2.2.4 Ethylene

St Amand and Randle (1989; 1991) found that wound healing was preceded by an increase in ethylene production. Measuring ethylene could therefore potentially form and indication of the wound healing process. Ethylene is thought to increase the peroxidase activity in wounded tissue (Matsuno and Uritani, 1972). Ethylene production during wound healing is probably stress induced (Randle and Woodson, 1986).

6.2.2.5 Wound healing efficiency: microbial invasion

Wound healing is known to protect wound against infection. Nielsen and Johnson (1974) examined wound infection by *Fusarium oxysporum*, after treatments of roots in water baths of different temperatures. The temperatures affected wound healing. The slow lignification and deeper location of wound phellogen favours the pathogen.

6.3 Materials and Methods

The experiments on wound healing included roots from the trials 1, 2, 3, 4, 9, 11, 12b, 13b and 14.

6.3.1 Wounding

Artificial wounds were inflicted using a potato peeler and a strip of periderm and cortex with a thickness of 1.7 mm was peeled off. In trials 1 and 2, the number of wounds per root was approximately in proportion to the root weight, i.e. 1 wound for roots less than 149 g, 2 wounds for roots weighing between than 150 and 249 g, etc. In trials 3, 4, 9, 11, 12b, 13b and 14 only one wound per root was made. In trial 3 and 4 the roots wounds were made along the total length of the root and in trials 9, 11, 12b, 13b and 14 the wounds measured approximately 2 x 5 cm.

6.3.2 Storage conditions

6.3.2.1 Storage set up

In trial 1 and 2 the roots from Kenya were kept under simulated tropical marketing conditions at NRI, UK, using dustbins equipped with storage racks. A pump provided air flow through water in the dustbins (see chapter 2, section 3.1).

In trial 3 and 4 in Ukiriguru, Tanzania, the roots were stored in woven polythene sacks (chapter 2, section 3.3). Every sack contained 1 root of each variety. Each root was assessed for weight every day. The level of CO_2 and O_2 were checked once per day just before opening the sack.

In trial 9, 11 12, and 13a the roots were kept in crates under natural storage conditions at NARL, Nairobi, Kenya, (chapter 2, section 3.4). The crates were lined with plastic for the first two days.

In trial 14 the roots were stored at NRI, UK where they were maintained at 3 different levels of humidity (high, intermediate and low, chapter 2, section 2.3.5).

6.3.2.2 Recording of conditions

In all trials the humidity and temperature were recorded using squirrel data loggers (Grant Instruments, UK) equipped with Vaisala probes (except trial 14). The probes were placed at about 10 cm from the root surface. Recordings were taken every hour or half hour. The recorded data are displayed in Appendix 1.

In trial 14 the temperature and humidity were recorded with Tinytalk miniature RH Dataloggers (Geminini, Chichester, UK). The recorded values are displayed in Appendix 1.

6.3.3 Efficiency of wound healing

6.3.3.1 Water vapour conductance

Porometer measurements were taken as described in chapter 4, section 2.3 using a PP-Systems porometer (PP-Systems, Hitchin, UK). Measurements were taken on the day of wounding (0) and at 3, 6, 8, 10 and 13 days thereafter on 5 to 10 wounded roots per storage time (Table 6.1). The size of the trial required that measurements of each data set were spread over 2 days. Hence 2 replicates were started: Rep 1 started on day 1, and rep 2 started on day 2. The data were analysed using analysis of variance at each time point in order to find cultivar differences. A regression analysis was carried out to find the relationship between time of curing and transpiration rate.

Table 6.1 Timing of porometer measurements upon sweet potato roots with respect to wounding and the day of the trial.

Day of trial		**1**	**2**	**4**	**5**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**
Days after wounding		**0**	**0**	**3**	**3**	**6**	**6**	**8**	**8**	**10**	**10**	**13**	**13**
Cultivars	**Rep**												
Trial 9	**1**	5		5		5		5		5		5	
	2		5		5		5		4		5		5
Trial 11	**1**	5		5		5		3		5		3	
	2		4		5		5		5		2		2

6.3.3.2 Microbial invasion

The susceptibility to *Rhizopus oryzae* (one of the most prevalent wound pathogens of sweet potato) was assessed for freshly cut and old wounds (3, 6 and 10 days) which were obtained from trial 9, 11 and 13b. Mycelial discs were cut with a 9 mm cork borer from the border of a 2-day-old PDA culture of *R. oryzae* and placed on the wound with the mycelial side facing down. The roots were incubated for 2 days in transparent polyethylene bags (40 cm x 50 cm) which were punctured with 16 holes for ventilation. The relative humidity and the temperature were recorded with Tiny Tag data loggers and were found to be 99% and 21– 25°C respectively.

The roots and tubers were then cut longitudinally through the point of inoculation and the dimensions of the rotted tissue was measured. The mean lesion size was calculated as the mean of the depth and the longitudinal diameter of the lesion (Duarte and Clark, 1993).

6.3.3.3 Incidence of rotting

The total number of roots that started to rot after wounding was recorded and for each cultivar the percentage of roots was calculated.

6.3.4 Lignification

6.3.4.1 Microscopy

Fresh sections of approximately 3 x 3 x 0.1 mm were cut with a razorblade, and stained with phloroglucinol (1% in ethanol 95%) for 1 minute. The sections were then transferred to concentrated HCl for 30 s and rinsed with water for 30 s. The thickness of the lignified layer was assessed at 100x enlargement using a microscope (Zeiss, Germany). The thickness of the lignified layer was expressed both in terms of the number of cell layers and as the actual thickness.

Tissue blocks of approximately 7 x 7x 7 mm were cut so that each block included both wound surface and native periderm and were fixed in FAA solution as described in chapter 4, section 2.2. After 2 months the tissue blocks were embedded in paraffin wax (Paraplast Plus, Sigma) as described in 4.2.2. Sections of 15 μm thickness were cut using a microtome. Before staining, the embedded sections were dehydrated in a series of

toluene (2x 100%) and ethanol (2x 100%, 1x 90%). The thickness of the lignified layer was assessed at 100x enlargement using a microscope (Leitz, UK) equipped with a graticule. Micrographs were taken using a Minolta X-700 camera, mounted on the microscope.

6.3.4.2 Assessment with the naked eye

Four thin cross sections (approx 0.1 mm thick) per wound were taken with a razorblade, and stained with phloroglucinol (1% in ethanol 95%) for 2 min. The sections were transferred to concentrated HCl for 30 s, than rinsed in water for 30 s.

Lignification was scored as shown in Table 6.2. A handhold lens giving an enlargement of x 20 was used if necessary. The lignification scores were used to calculate the lignin index and the presence of lignin and the completion of lignification were used to relate wound healing efficiency with lignification.

Table 6.2 Scores for lignification of sweet potato wound sections

	Score	Completeness of the lignin layer		
	Lignification score	Presence of lignin	Completeness of lignification	Distribution of lignin in wound = lignin
Complete lignification	1	1	1	
Patchy lignification	0.5	1	0	
No lignification at all	0	0	0	

6.3.4.3 Lignin index

The lignin index was defined as the mean of the lignin scores. The lignin index is specific for the conditions at which it is measured. During trial 9, 11, 12a and 13b the scores between 3 and 17 days after wounding were used and in trial 14 the scores were taken from day 3 and 6.

6.3.5 Dry matter content

6.3.5.1 Dry matter contents of the cultivars

The dry matter contents of the cultivars were assessed using three randomly selected roots per cultivar. Parenchyma was diced or sliced and about 20 g was dried in an oven at 80°C for 48 hours. Duplicate measurements were taken. The dry matter content was determined for each of the cultivars in trial 9, 11, 12, 13b and 14 according to equation 6.1.

$$DM = 100\% * M_{dry} / M_{fresh} \qquad \textit{Equation 6.1}$$

DM = Dry matter content

M_{dry} = Mass of the dried parenchyma

M_{fresh} = Mass of the freshly cut parenchyma

6.3.5.2 DM contents of the individual roots

During trial 14 the dry matter contents of individual roots were determined in the following way: Weight losses between wounding and after wounding were recorded . After assessment for lignification, the remaining root was sliced and the DM content determined. The DM content before wounding was estimated in the following way:

$$DM_{u\,t=0} = DM_{w\,t=6} * M_{w\,t=6} / M_{w\,t=0} \qquad \textit{Equation 6.2}$$

$DM_{u\,t=0}$ = Dry matter content of the unwounded root

$DM_{w\,t=6}$ = Dry matter content of the root 6 days after wounding

$M_{w\,t=0}$ = Mass of the wounded root immediately after wounding

$M_{w\,t=6}$ = Mass of the wounded root at 6 days after wounding

This calculation is based on the assumption that most of the weight loss after wounding consists of water loss as it was shown in chapter 3 that only 10% of weight loss is typically accounted for by carbohydrate consumption.

6.3.6 Statistical analysis

A summary of the measurements to investigate the role of wound healing in this chapter on the roots is given in Table 6.3.

Table 6.3 Overview of experiments to investigate wound healing used in trial 1. 2, 3, 9, 11, 12a, 13b and 14.

	Trial							
	1	**2**	**3**	**9**	**11**	**12a**	**13b**	**14**
Lignification								
Microscopy (M)	M	M						
Scores (S)			S	M	M			
Lignin Index (LI)	LI	LI		LI	LI	LI	LI	LI
Water loss through wound								
Weights (W)			W	W	W		W	
Porometer (P)				P	P			
Microbial invasion								
Incidence (I)				I	I			I
Dimensions (D)				D	D			
DM (DM)				DM	DM	DM	DM	DM

Cultivar differences for all characteristics were analysed using analysis of variance. Contingency tables were used to determine the association between lignification and weight loss, transpiration rate and susceptibility to *R. oryzae*. Categories were made for the level of weight loss and transpiration based on their distribution. For susceptibility to rotting the 2 categories constituted no rotting and rotting. The significance of the association was assessed using the Pearson Chi Square tests in Genstat.

Relationships between the transpiration rate and storage time, and between the lignin index and DM content were assessed using linear regression in Genstat. The mean values of each cultivar were taken.

6.4 Results and discussion

6.4.1 Physiology of wound healing under tropical conditions

6.4.1.1 Tissue types in the wound of sweet potato

Plate 6.1 presents a micrograph of a cross section of a sweet potato wound surface in which the cell types associated with wound healing are shown. Immediately under the cut surface are the dead cells, as a result of desiccation, which takes place in the first days after wounding between day 1 and 3. Below this the lignified cells are visible which occurs between 1 and 5 days after wounding. The wound periderm, which forms after about 7 days is formed underneath this layer.

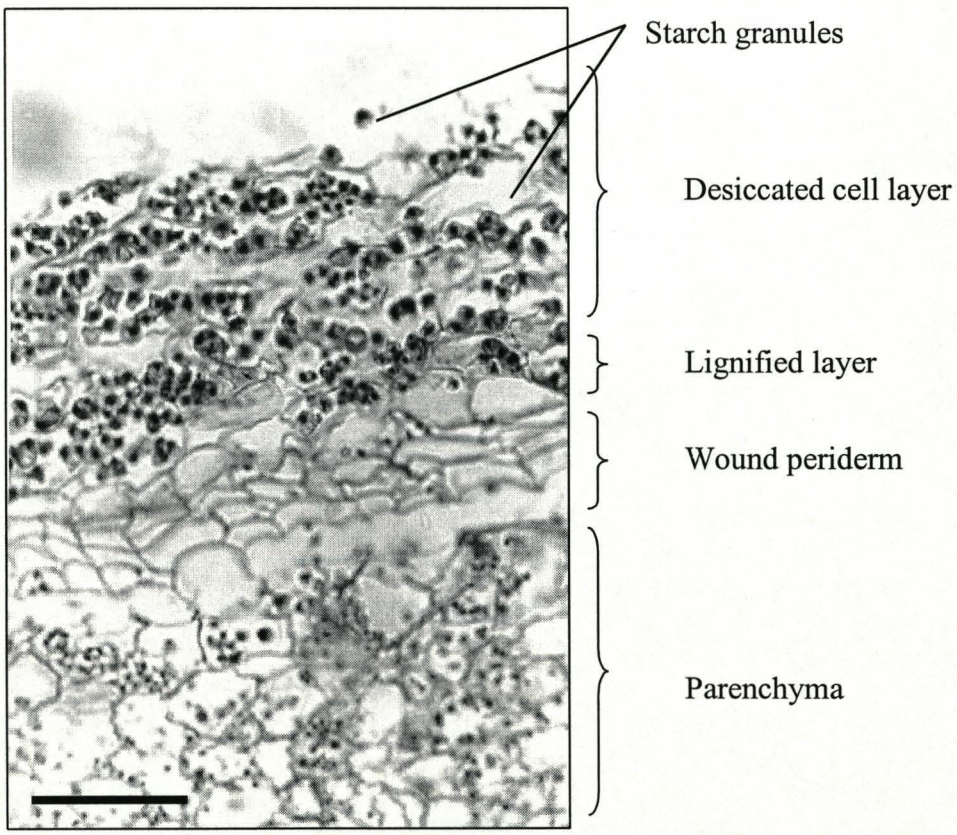


Plate 6.1 **Section of a wound from the sweet potato cultivar Yan Shu 1 at 13 days after wounding, stained with safranin and fast green, showing the desiccated cell layers, the lignified layers and wound periderm formed (x100). The bar represents 100 μm.**

6.4.1.2 Desiccated cell layers

The desiccated cell layer is defined as the layer between wound surface and the lignified cell layers. The cells are flattened, probably through moisture loss, but the cell structure is still visible. The desiccated cell layer has a white appearance which is due to the high density of starch granules (Plate 6.1).

The thickness of the desiccated cell layers varied among cultivars but also among individual roots of the same cultivar. Plate 6.2a-e illustrate the differences encountered among cultivars and Figure 6.2 presents the development of the thickness of desiccated cell layers. For Zapallo, the desiccated cell layers were very thin, while the cultivar KSP 20 had a much thicker desiccated cell layer. For SPK 004 a lignin layer was not always formed (Plate 6.2d) , and the limits of desiccation were not easy to define.

For potato, only one desiccated cell layer was observed on top of the suberised layer (data not shown). This emphasises how the physiology of potato differs from that of sweet potato. Lulai and Orr (1995) reported that in potatoes waxes are deposited within 2 days after wounding. Possibly these waxes prevent desiccation. In sweet potato waxes might not be are deposited as quickly, and desiccation therefore takes place for longer time. The results obtained upon the transpiration rate (see 6.4.3), in which potato tubers had a steeper decline in the transpiration rate than sweet potato, support this hypothesis.

Some variability in the thickness was also observed according to the storage conditions. Plate 6.3 shows root slices taken from 8 cultivars which were stored at different relative humidities (97%, 65%, 58%) at 3 and 6 days after harvest. Not surprisingly roots stored at lower humidity show greater desiccation. These layers consisted of thick crusts that were difficult to cut and was found in the cultivars SPK 004, Kemb 10, KSP 20 and Caplina. Much thinner layers were found for the cultivars Zaplallo, Salyboro, Yan Shu 1 and Julian. This is in agreement with Strider and McCombs, (1958) who observed a thick desiccated cell layer at a depth of 17 layers if the roots were kept at 21°C and 60% RH, compared to a depth of 4 to 6 layers at curing conditions.

Descited cels

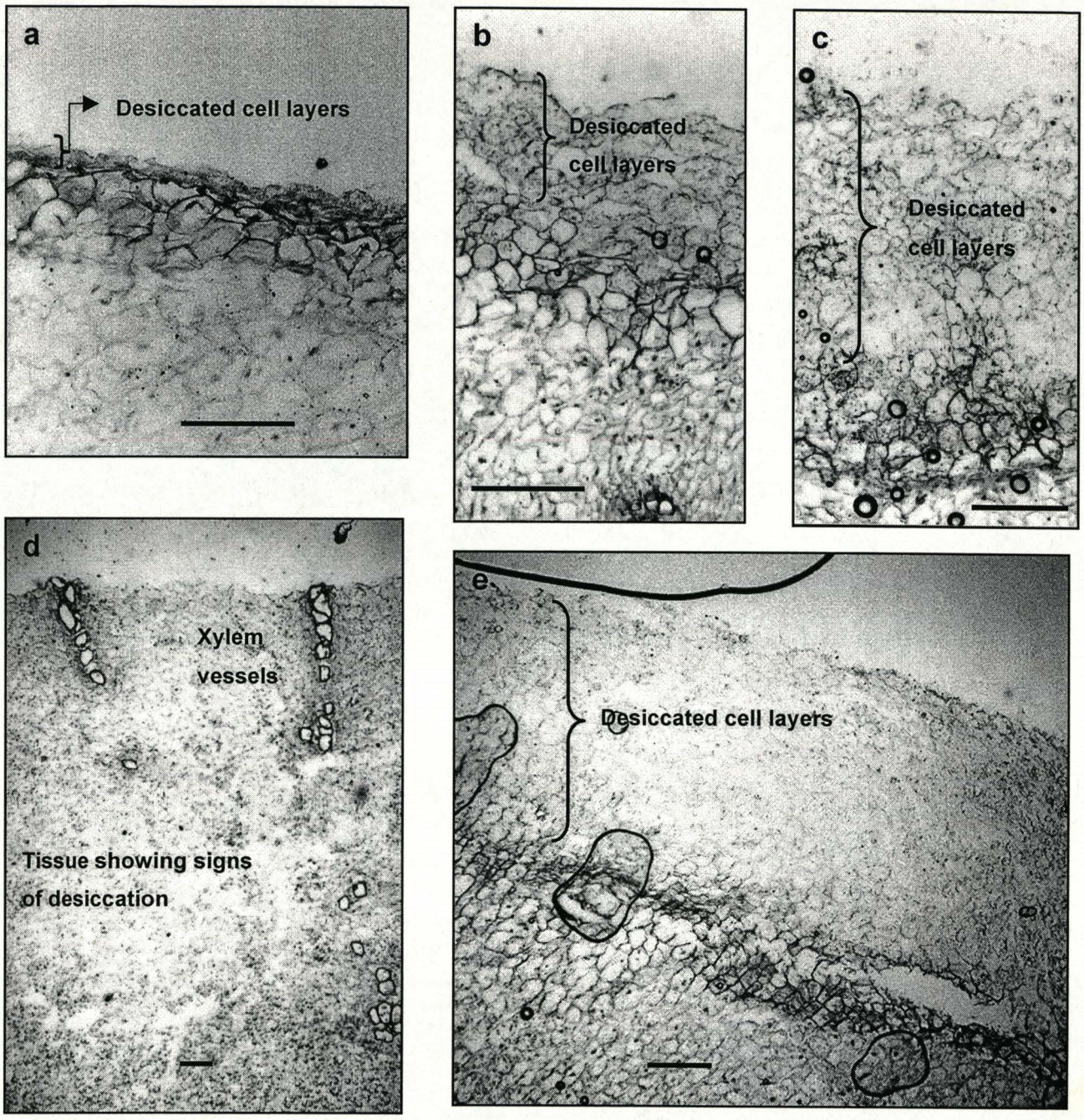


Plate 6.2 **Variability in the depth of desiccation.Typical sections through sweet potato wounds at 6 days after wounding when the roots were kept at 71.1% RH and T = 20.9 ± 1.6. Sections were stained with phloroglucinol (1% in ethanol 95%) and HCl concentrated. Magnification: x 40 or x 100. The bar represents 100 μm.**

a) Zapallo: thin desiccated cell layer (x 100)
b) BP1-SP-2: 5 to 7 desiccated cell layers (x 100)
c) Yarada: 16-20 desiccated cell layers (x 40)
d) SPK 004: no lignified cell layers (x 40)
e) KSP 20: 20 to 25 desiccated cell layers above patchy lignification (x40)

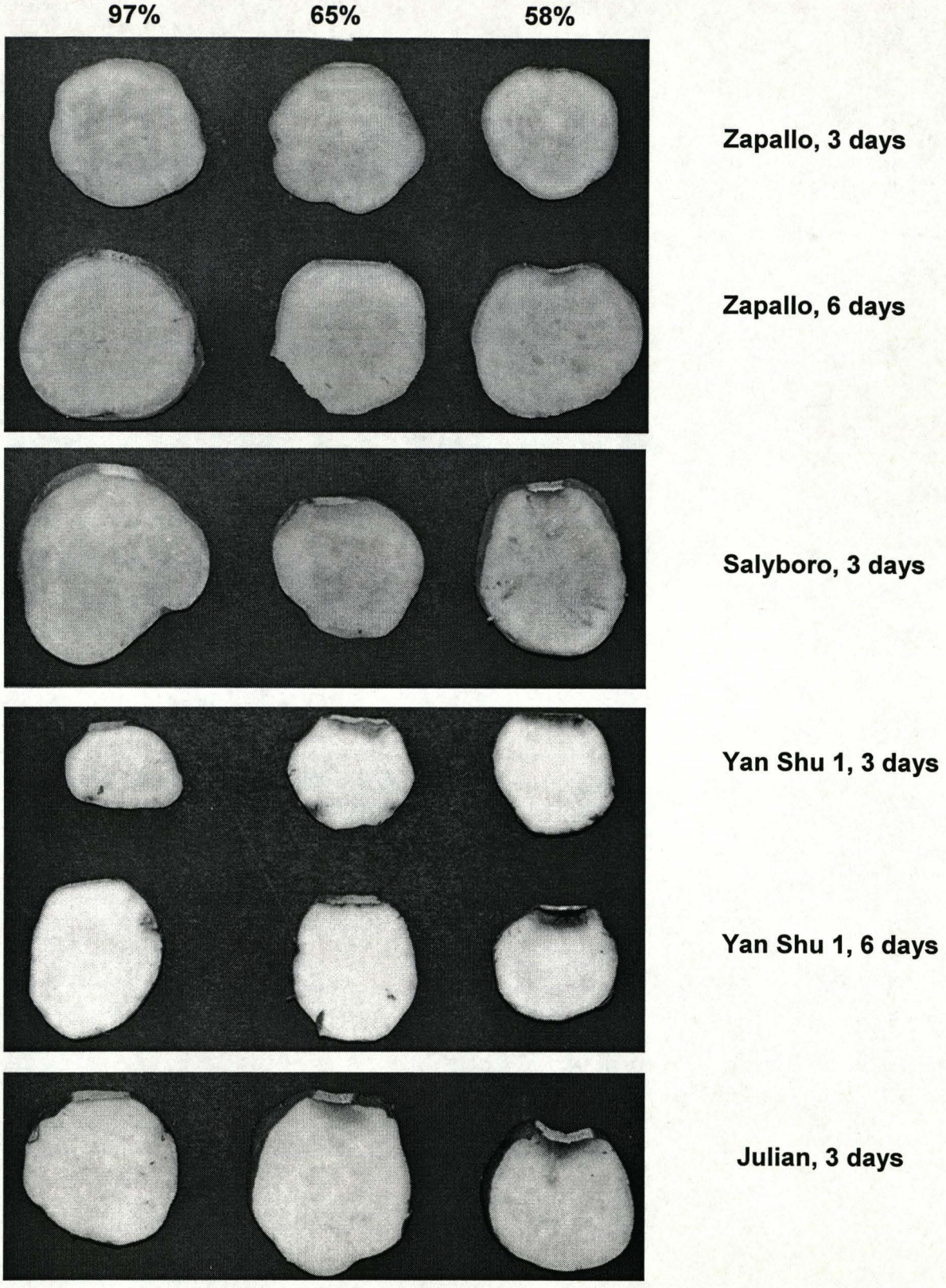


Plate 6.3a **Variability in depth of desiccation depending on cultivar and relative humidity. Slices of sweet potato with the wounds . From left to right: 97% RH, 65% RYH, 58% RH. (Zapallo, Salyboro, Yanshu, Julian)**

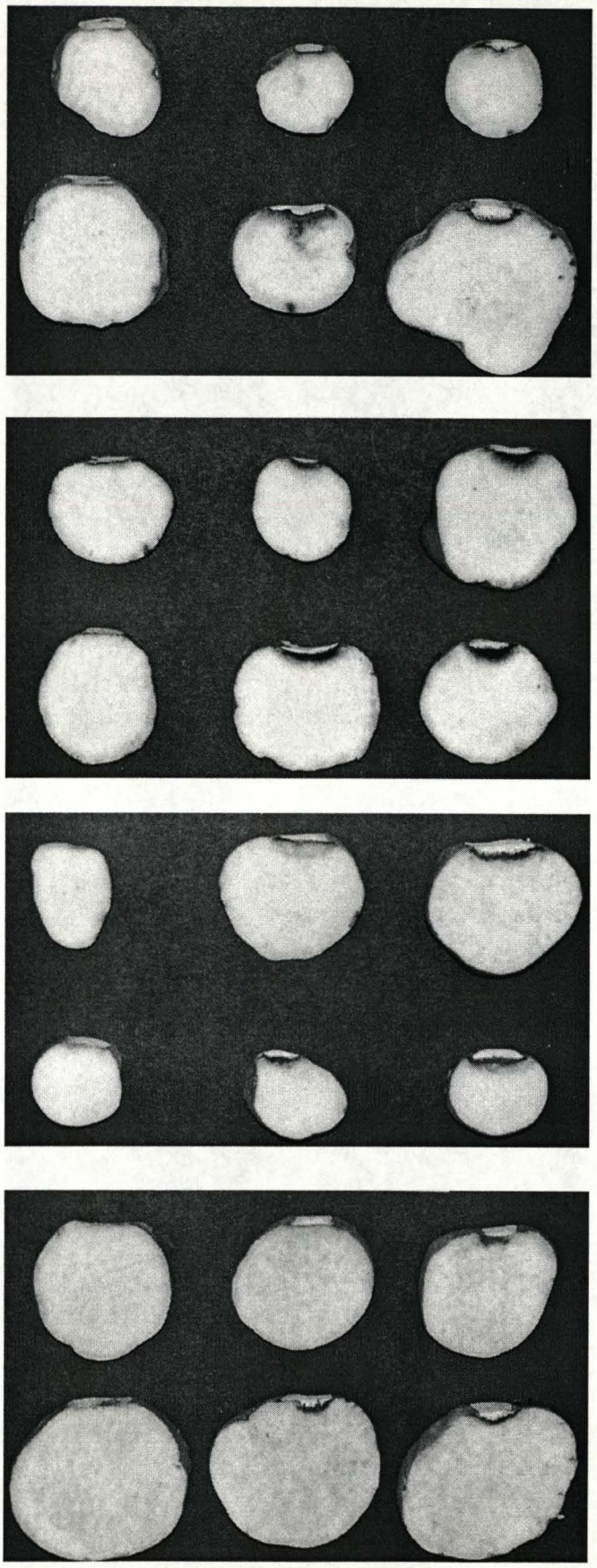


Plate 6.3b **Slices of sweet potato with the wounds . From left to right: 97% RH, 65% RYH, 58% RH. Caplina, KSP 20, Kemb 10, SPK 004)**

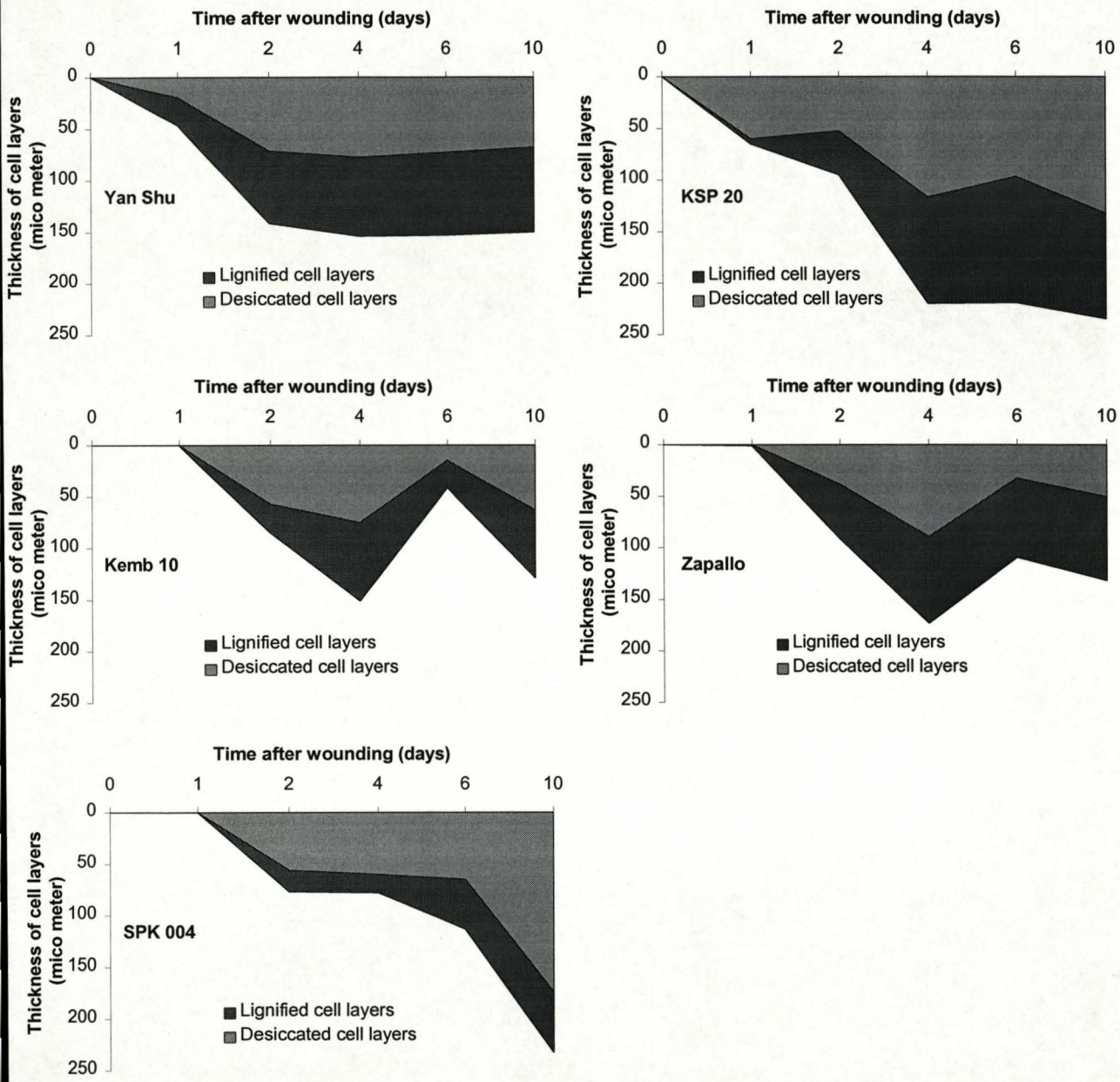


Figure 6.2 The thickness of the desiccated cell layers and lignin layers during the first 10 days after storage for 5 cultivars of sweet potato. Storage conditions: 26°C and 70-80% RH.

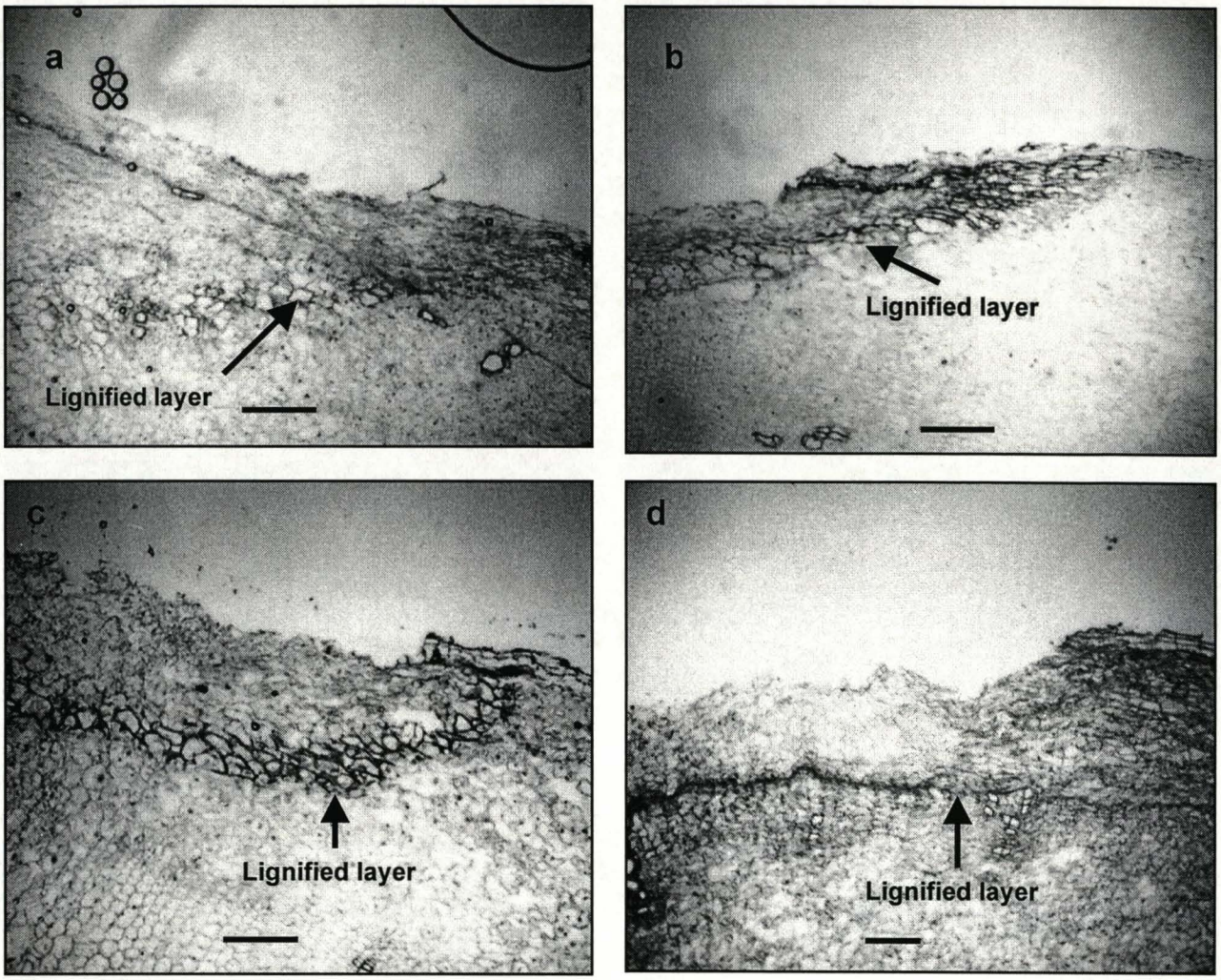


Plate 6.4 **Lignification initiates at the wound boundary.**
The onset of the lignin layer in wounds of sweet potato at 6 days after wounding. The section were taken from a) Salyboro, b) Zapallo, c) Kemb 10, d) KSP 20. The bar represents around 200 μm. Sections: 15 μm thickness, stained with Phloroglucinol/HCl, which stains the lignin red.

6.4.1.3 Lignification (Phloroglucinol/ HCl staining)

Below the desiccated cell layers cell walls start thickening which is referred to as lignification or suberisation. Although it is not clear how much constitutes of suberin or lignin, in sweet potatoes this layer stains with phloroglucinol/HCl. The current experiments on lignification were conducted using phloroglucinol/HCl as a stain.

Plate 6.4 presents some examples of the onset of lignified layer. Lignification started at the periphery of the wounds under the periderm, and the lignin layer develops towards the centre of the wound. In roots with patchy lignification, lignin generally occurred near the periderm (Plate 6.4d) but discontinued in the centre of the wound. This might be accounted for by the fact that the wound is likely to be deeper in the centre.

In order to compare cultivars for wound healing initially the thickness of the lignified layer was used as a measure of differences in wound healing among sweet potato cultivars. The experiments were carried out under simulated marketing conditions and not under ideal storage conditions. Figure 6.3 a and b show the number and the thickness of lignified cell layers observed in freshly hand cut sections for 5 cultivars after artificial wounding.

Lignification started after 1 day for some cultivars, but in most cases it started after 3 days. Both the number of lignified layers and the thickness increased during the first four days after wounding. After 4 days however, the number of lignified layers remained steady, around 3 to 5 layers for the cultivars Zapallo, KSP20 and Kemb10. For Yan Shu 1 the mean number of lignified layers was slightly lower.

These findings are in correspondence with the findings of Walter and Schadel (1982) who found 2.6 layers of suberised cells at 4 days after wounding. Walter and Schadel (1983) reported that the number of lignin layers at 3 and 5 days after wounding (1.4 layers of suberised cells) increased to 4.3 layers of suberised cells after 5 to 7 days under ideal curing conditions. However the results disagreed with the results of St Amand and Randle (1991), who described an almost linear increase in the number of lignified cell layers.

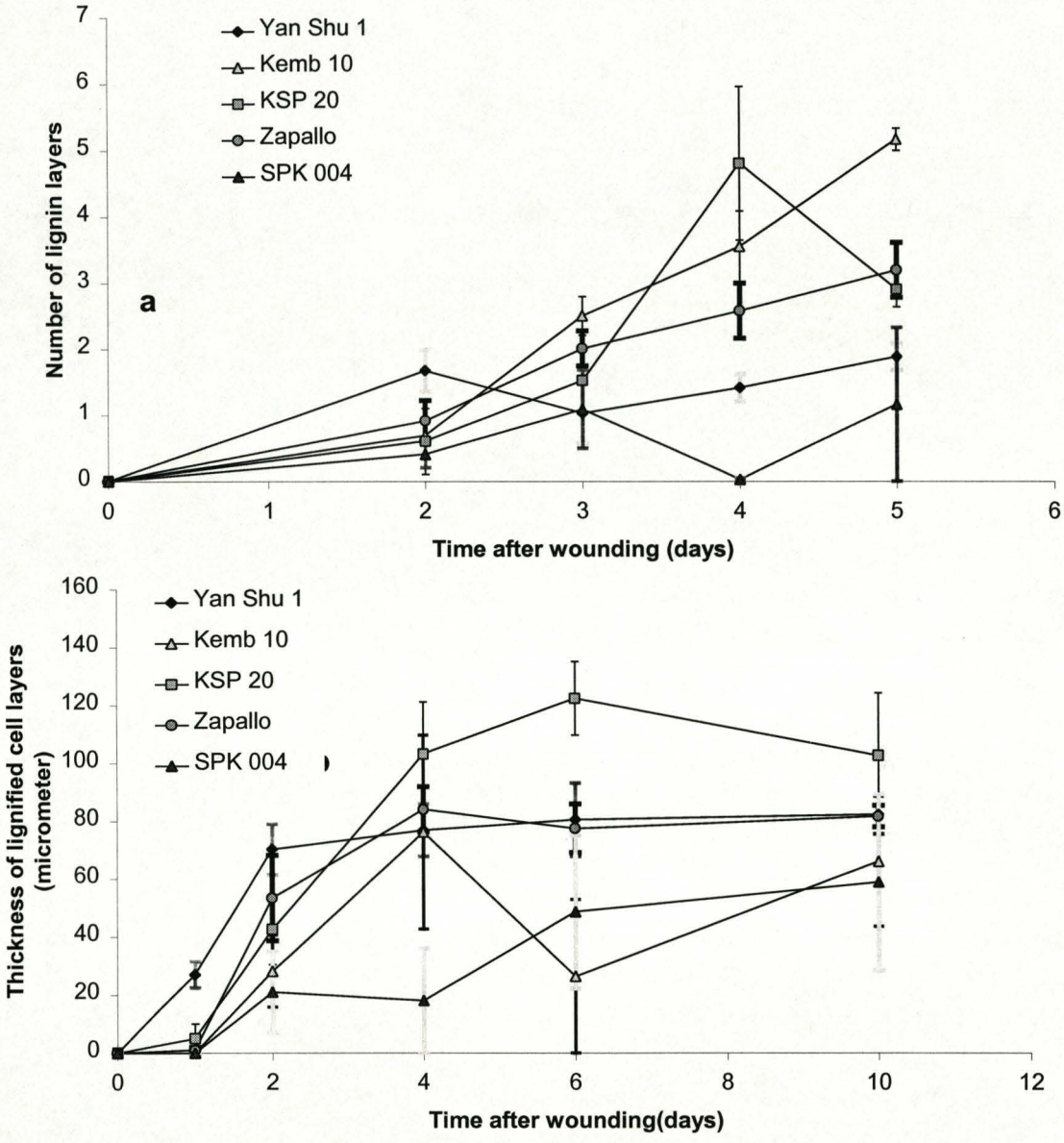


Figure 6.3 The mean number of lignified layers and thickness of the lignified layers in the root during Trial 1 (a, number of layers) and Trial 2 (b, thickness of lignified layers). Each value is the mean of 5 wounds, and 20 measurements. Storage conditions (26°C, 70-80% RH, high ventilation)

Sometimes lignification occurred in a patchy pattern, having 5 to 6 lignified layers at some places, but no lignification at others (Plate 6.2.e) and some roots completely failed to produce lignin (Plate 6.2d). This was the case in 40% of the roots of SPK004 and 55% of the roots in Kemb10. Failure of lignification coincided with development

of hard wound tissue. These cultivars were also poor in storability as was determined in chapter 3. Failure of lignification as a cultivar related characteristic been has not previously described in the literature, but could be a key factor in storability under tropical marketing conditions. This lead to the need of a measuring technique that assesses the probability that wound healing occurs. The lignin index provides this information and the results are presented in section 4.2 of this chapter.

6.4.1.4 Formation of the wound periderm

Although no quantitative measurements were taken, it was observed that wound periderm formed under the lignified layers. The wound periderm autofluoresces blue (Plate 6.5) in a similar way to normal periderm (chapter 4, section 4.2). Unlignified wounds did not form a wound periderm (Plate 6.2d) confirming the findings of other scientists that the formation of the lignified layer is necessary for development of the wound periderm (Walter and Schadel, 1982)

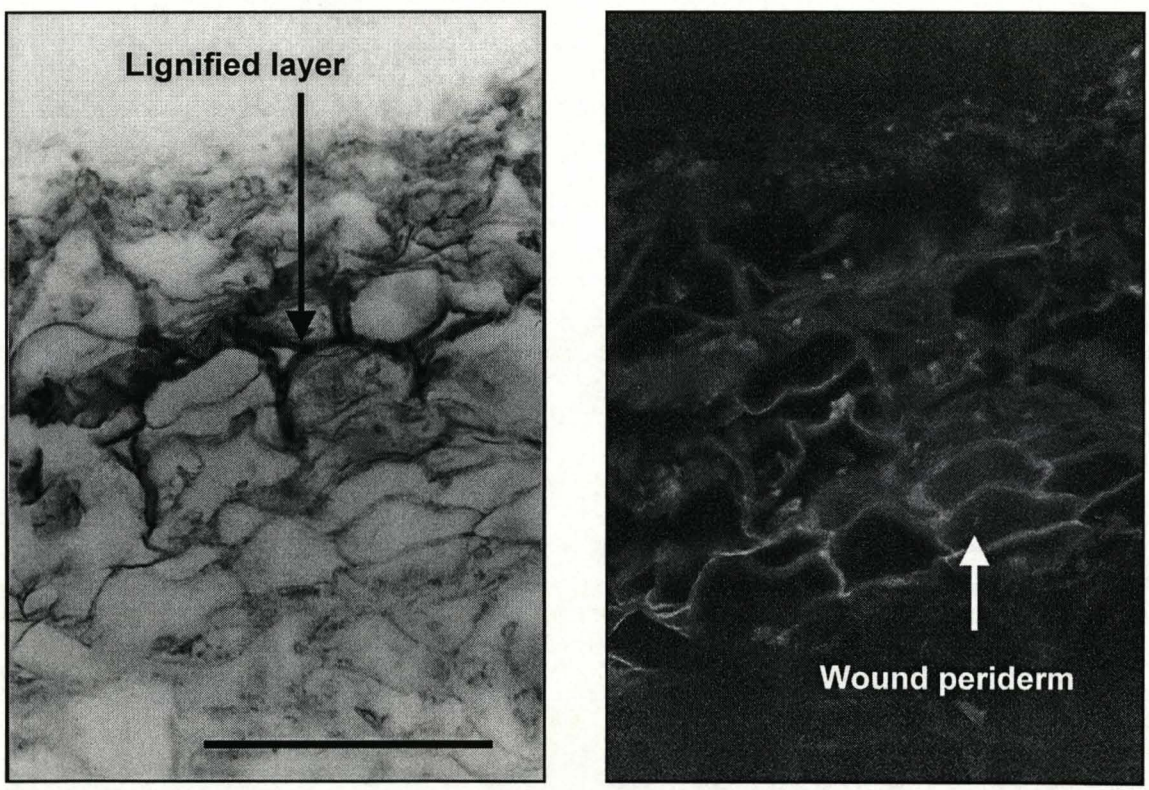


Plate 6.5 Formation of wound periderm under the lignified layer stained with phloroglucinol/HCl. a) bright light b) UV light (400x). Bar = 100μm.

6.4.2 *The Lignin Index*

6.4.2.1 Cultivar differences in lignin index

The lignin index was defined as the probability that wound healing occurs, and is measured by taking the mean score of lignification. Table 6.4 presents the lignin indices obtained from several sweet potato cultivars. The cultivars with a consistently high lignin index were Zapallo, Yan Shu 1 and BP1-SP-2. Consistently poor lignin indices were observed for the cultivars SPK 004, Kemb 10 and KSP 20, while the lowest lignin indices were observed for the cultivars Naveto, Sowola and NIS/94/320.

Table 6.4 The lignin index of 16 sweet potato cultivars as determined in 8 trials.

	Trial 1	Trial 1 (4 wks)	Trial 2	Trial 2 (6 wks)	Trial 9	Trial 11	Trial 12b	Trial 13b
Temperature °C	**26**	**26**	**26.1**	**26.1**	**20.9**	**20.1**	**22.3**	**22.7**
RH (%)	**82.2**	**82.2**	**73.2**	**73.2**	**71.1**	**75.9**	**67.3**	**64.7**
Zapallo	1	0.82	1	0.95	0.89	1		0.79
Yan Shu 1	0.8	0.9	1	1	0.96	0.98	0.96	0.95
BP1-SP-2					0.93	1		0.87
Salyboro					0.8	0.95		0.67
Julian					0.61	0.95		0.69
Caplina					0.74	0.9		0.56
Yarada					0.57	0.9		0.58
Santa Amaro							0.6	
KSP 20	0.85	0.91	0.8	0.9	0.3	0.58	0.09	0.33
Kemb 10	1	0.6	0.45	0.16	0.39	0.79		0.25
Mugande							0.32	
SPK 013							0.3	
SPK 004	0.29	0.35	0.38	0.3	0.15	0.31		0.15
NIS/94/320							0.25	
Sowola							0.13	
Naveto							0.06	

Table 6.5 gives the lignin indices for 13 sweet potato cultivars during trial 14, at the relative humidity of 58% and 65%. The lignin indices were significantly higher at 65% RH than at 58% RH ($P < 0.001$). Zapallo had consistently the highest lignin index, followed by Yan Shu 1, Yarada and BP1-SP-2, and consistently low lignin indices were observed for SPK 004 and Kemb 10 (and to some extend for Caplina).

Table 6.5 The lignin indices for 13 sweet potato cultivars during trial 14 (RH = 58 and 65%, T = 26°C). Each lignin index was determined using 5 to 10 roots, with 4 scores per root.

	RH 58%	RH 65%
Zapallo	0.85	1
Yan Shu 1	0.83	0.93
Yarada	0.75	0.89
BP1-SP-2	0.59	0.92
SP/93/3	0.47	0.80
Sinia B	0.49	0.75
Julian	0.43	0.75
Salyboro	0.46	0.69
KSP 20	0.5	0.55
SPN/0	0.34	0.69
Caplina	0.5	0.32
Kemb 10	0.03	0.21
SPK 004	0.05	0.08
Mean	**0.479**	**0.664**
Cultivar effects:		
P <	0.001	0.001
LSD =	0.249	0.283
Combined RH's:		
Cultivar: P < 0.001, LSD: 0.1760		
Relative Humidity: P < 0.001, LSD: 0.2489		
Cult * RH: P = 0.348		

6.4.2.2 Lignin index in relation to weight loss

Figure 6.4 presents the lignin index and weight loss of wounded roots after 4 days for 29 cultivars of sweet potato for trial 3. It was observed that under these conditions most of the wounds were lignified. It was also noted that a lower weight loss was recorded for cultivars with a lignin index of 1.0. To test whether this association was significant the individual roots within categories were counted and contingency table formed (Table 6.6). A significant association was found between lignification and weight loss, and roots with unlignified wounds showed higher weight losses.

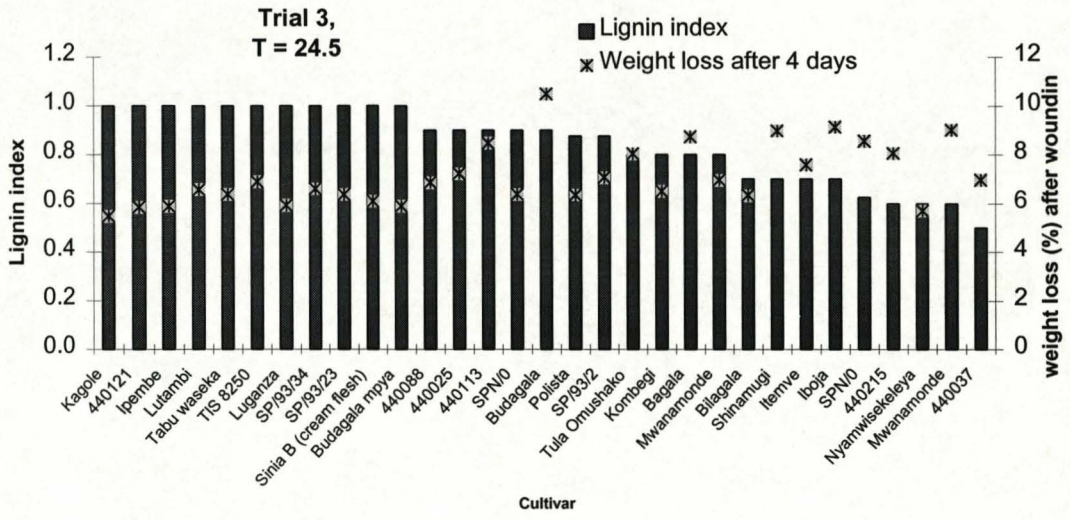


Figure 6.4 **Mean lignification score and weight loss after 4 days of 29 sweet potato cultivars, grown in Tanzania, and stored in polythene bags (T = 24.5°C).**

Table 6.6 **Contingency table showing the number of roots with lignified wounds versus unlignified wounds and their weight losses after 4 days, using 29 sweet potato cultivars. Measurements were taken in trial 3.**

	Lignification score			
Weight loss (%) after 4 days	**No lignin or patchy lignification**	**Continuous lignified layer**	**χ^2-Value**	**P value**
3.7 < w < 6.1	3	45	18.59	< 0.001
6.1 < w < 7.5	8	42		
7.5 < w < 14.6	20	29		

6.4.3 Lignification in relation to rate of transpiration

6.4.3.1 Profiles of transpiration rate during wound healing

The transpiration rate as measured with a porometer was highest immediately after wounding and ranged between 200 and 400 $mmol \cdot m^{-2} \cdot s^{-1}$ for all sweet potato roots and potato tubers (Figure 6.5). This is not surprising as the surface of the roots is still wet and no barrier is formed in this short time. No significant differences were observed among cultivars for the transpiration rate through fresh wounds (Appendix, Table 6)

After 3 days the transpiration rates had decreased considerably in both. In trial 11 the transpiration rate after 3 days was much higher than in trial 9. This is inevitably related to the natural storage conditions, which were different in both cases. The transpiration rate decreased much more rapidly in trial 9 than in trial 11. It is not clear why this happened. The most extreme decline in transpiration rate was observed for the potato cultivars. Their transpiration rate was between 36.2 and 46.3 $mmol \cdot m^{-2} \cdot s^{-1}$ which is half of the transpiration rate through sweet potato wound. This is in correspondence with the steep decline found by Lulai and Orr (1995) and reported that the decline in vapour conductance, was associated with the deposition of waxes.

Although the absolute differences in transpiration through wounds were not large, significant differences were noted among sweet potato cultivars. The transpiration rates for Kemb 10 and SPK 004 were in all cases significantly higher than for the cultivar Zapallo, and in most cases showed a significantly higher transpiration rate than Yanshu.

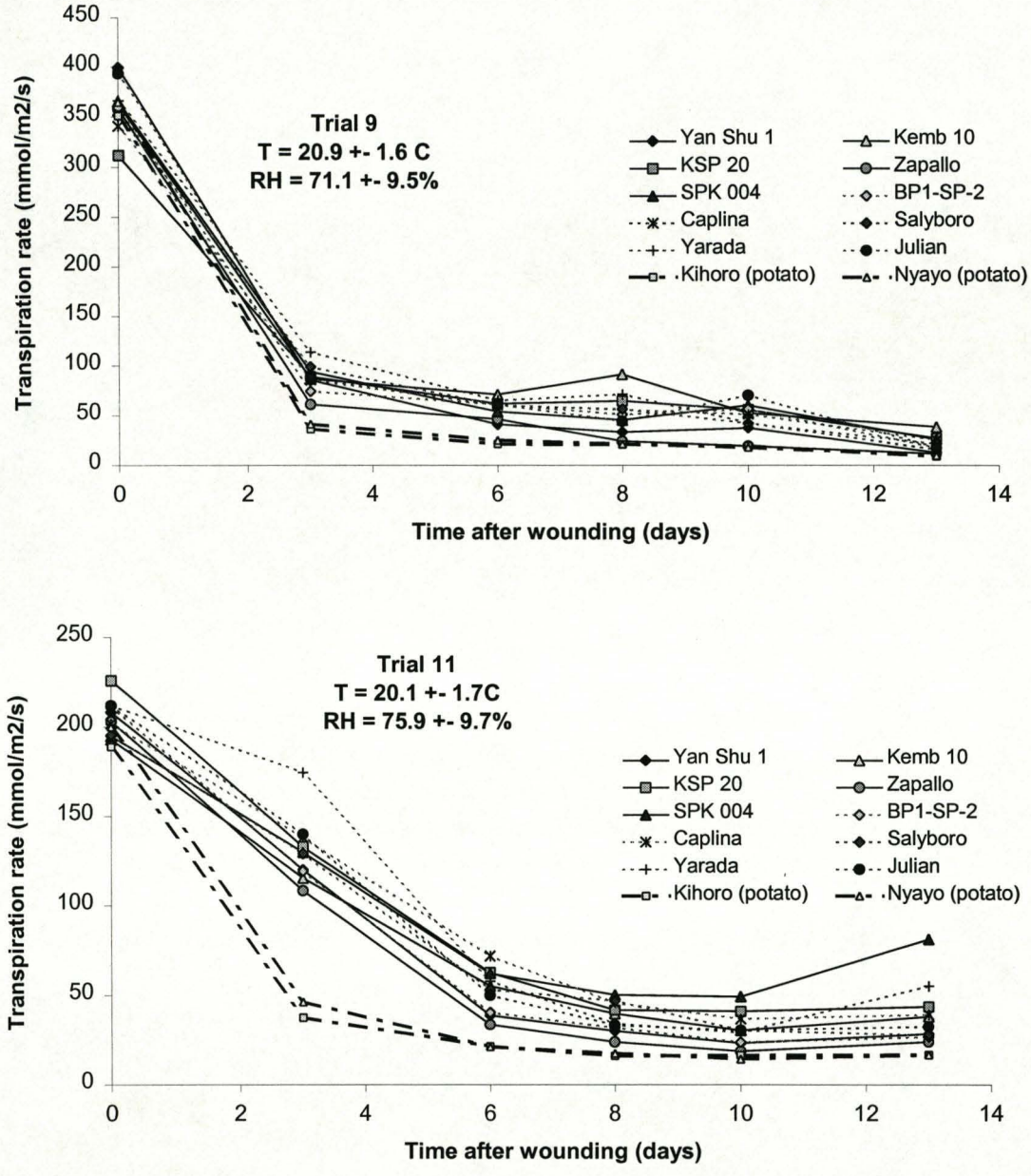


Figure 6.5 Transpiration rate across artificially inflicted wounds on 10 sweet potato and 2 potato cultivars during trial 9 (a) and trial 11 (b). Each value is the mean of 10 measurements taken with a porometer at the wound site.

The regression between storage time and transpiration rate was significant (Appendix 6.2; $P < 0.001$, $R^2_{adjusted} = 0.29$). The addition of cultivar as grouping factor in the regression analysis increased the significance of the model ($P < 0.001$, R^2 adjusted = 0.461). There was also a significant interaction between storage time and cultivar.

6.4.3.2 Lignification to prevent water loss

The association between the presence of lignin and transpiration rate was assessed using the data of individual roots irrespective of the cultivar. The distribution of the transpiration rate was divided into 3 categories (as low, intermediate and high) and lignification was divided into 2 categories, according to the completeness of lignification (Table 6.7).

Table 6.7 Association between lignification and the rate of water loss through wounds of 3, 6, 8, 10 and 13 days. Data collected from Trial 9.

					Counts of roots with			
Time after wounding	**Transpiration (T) (mmol/s/m2)**				**No lignin or Patchy lignin**	**Continuous Lignin layer**	**χ^2-Value**	**P value**
3 days	Low	76.2	> T		5	9	3.26	= 0.196
	Intermediate	76.2	< T <	89.2	7	4		
	High		T >	89.2	10	5		
6 days	Low	43.2	> T		0	12	11.80	= 0.003
	Intermediate	43.2	< T <	57.8	8	4		
	High		T >	57.8	5	8		
8 days	Low	37.25	> T		3	9	17.20	< 0.001
	Intermediate	37.25	< T <	63.75	1	10		
	High		T >	63.75	10	1		
10 days	Low	29.6	> T		1	9	8.36	= 0.015
	Intermediate	29.6	< T <	69.4	3	8		
	High		T >	69.4	7	3		
13 days	Low	14	> T		2	9	8.71	= 0.013
	Intermediate	14	< T <	19.4	0	12		
	High		T >	19.4	6	6		

Lignification was significantly associated with a low transpiration rate at 6, 8, 10 and 13 days after wounding. Only at day 3 there was no association with the transpiration rate. Probably the wound healing process was not completed. It might indicate that actually a wound periderm is necessary to reduce transpiration, and a wound periderm generally starts to form after 5 to 6 days (St Amand and Randle, 1991) It should be noted that unhealed wounds also decreased in their transpiration rate. This is probably the result of the desiccation of the cells which form a barrier for water loss.

6.4.4 Lignification in relation to microbial infection

6.4.4.1 Artificial inoculation with *Rhizopus oryzae.*

The resistance of the wound surface against microbial invasion in sweet potato and potato was tested on wounds that were 3, 6 and 10 days old and compared to freshly cut wounds. The roots were inoculated with an agar disc containing active *Rhizopus oryzae.* Figure 6.6 presents the mean dimension of fungal lesions in old and new wounds.

Older wounds (>3 days) were less susceptible to fungal invasion than freshly cut wounds($P < 0.001$), except SPK 004 and the susceptibility decreased with the age of the wound (3 > 6 > 10 days). Potato wounds infected 3, 6 or 10 days after wounding were not susceptible to *R. oryzae.* During Experiment 1 none of the sweet potato roots were invaded after 6 days of healing, but this was not consistent in Experiment 2 and 3. The cultivar SPK 004 was the only cultivar that was consistently invaded by the fungus. This was consistent with the fact that SPK 004 often had to be removed from the wound healing and weight loss trials because of rotting or mouldiness.

Among the freshly cut wounds significant cultivar differences existed in the size of the lesion (Table 6.8). The cultivars BP1-SP-2, Caplina, Salyboro and Yarada had significantly larger lesions than Yan Shu 1, Julian and SPK 004 or the potato cultivars Kihoro and Nyayo.

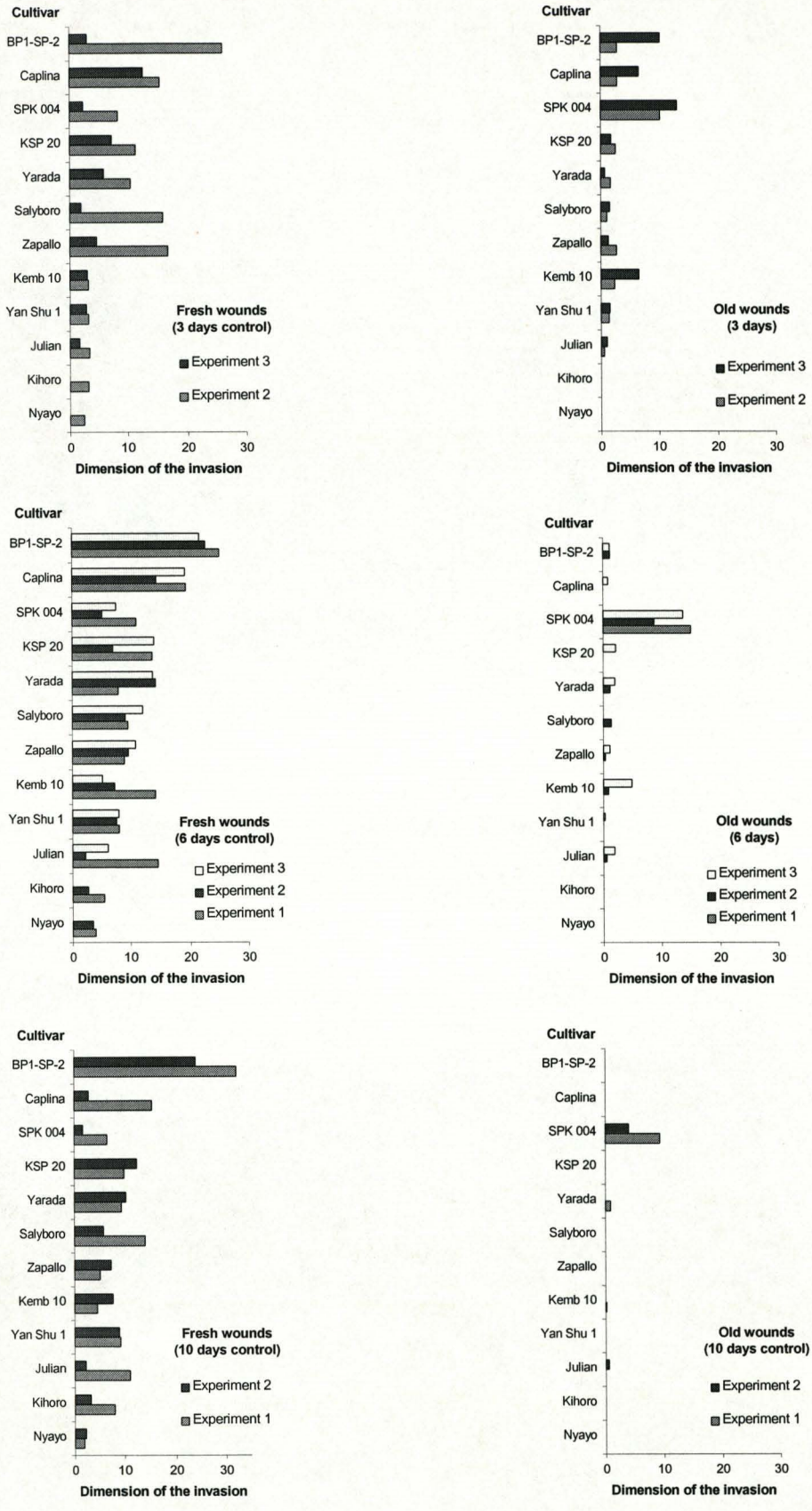


Figure 6.6 Dimensions of lesions of *R. oryzae* in 3, 6 or 10 days old wounds and controls (freshly cut wounds). Active mycelium was placed on the wound and the roots were incubated in plastic bags to maintain humidity (RH =95%; T = 21-25°C) (LSD_{exp1} = 6.96; LSD_{exp2}= 5.74; LSD_{exp3} = 7.02)

Table 6.8 Mean size of lesions after inoculation with *R. oryzae* on freshly cut wounds

	Mean size of rotted lesion
BP1-SP-2	20.0
Caplina	19.4
Salyboro	16.5
Yarada	14.7
Zapallo	13.5
KSP 20	12.0
Kemb 10	11.0
SPK 004	9.8
Julian	9.5
Yan Shu 1	8.6
Kihoro	6.4
Nyayo	5.5
P	< 0.001
LSD Min rep	6.19
Max-min	5.74
Max	5.24

6.4.4.2 Incidence of rotting without artificial inoculation

Table 6.9 presents the percentage of roots that had started to rot during the wound healing trials 9, 11 and 14. Most incidences of rotting occurred for the cultivar SPK 004 and the percentages were 7, 24 and 11% respectively. The least susceptible to rotting were Julian, Yan Shu 1, and Salyboro.

Table 6.9 Percentage of roots that had rotted after wounding without artificial incubation during trial 9, 11 and 14.

	Trial 9 % roots rotted	Trial 11 % roots rotted	Trial 14 % roots rotted
Julian	0	0	0
Yan Shu 1	0	0	1
Salyboro	1	0	0
KSP 20	1	1	0
Zapallo	1	1	0
Yarada	4	1	0
BP1-SP-2	1	1	4
Kemb 10	0	3	8
Caplina	4	3	9
SPK 004	7	24	11
Kihoro (potato)	0	0	
Nyayo (potato)	3	0	

In trial 14, it was observed that rotting occurred more often under low humidity storage conditions than at high humidity. This relates to the fact that the rate of wound healing is higher at 97% RH, which is in correspondence with the findings of Nielsen and Johnsen (year) who established that susceptibility to pathogens is lower when wound healing is quick. Plate 6.6 shows roots of cultivar SPK 004 were more susceptible to rotting when stored at 58% RH than at 97% RH.

6.4.4.3 Lignification to prevent rotting

The lignin scores and the dimensions of rotting were assessed for each individual root and analysed as such. Hence for day 3 and day 6 different categories were made as presented in Table 6.10.

Table 6.10 Contingency table using the incidences of roots rotting and/ or lignification. In (A) patchy lignified roots were grouped with complete lignified roots, and in (B) patchy lignification was grouped with 'no lignin'.

Time after wounding	Rotting	(A) Presence of lignin		(B) Completeness of lignified layer	
		No Lignin	Patchy lignin Complete lignification	- No lignin – Patchy lignin	Complete lignification
Day 3	No Rotting	11	26	14	23
	Rotting	18	31	28	21
		Pearson Chi Square = 0.46 P = 0.496 Fisher's exact test: P = 0.6455		Pearson Chi Square = 6.71 P = 0.010 Fisher's exact test: P = 0.01544	
Day6	No Rotting	5	28	5	28
	Rotting	15	19	26	8
		Pearson Chi Square = 3.14 P = 0.076 Fisher's exact test: P = 0.0861		Pearson Chi Square = 25.33 P < 0.001 Fisher's exact test: P < 0.001	

There was no significant association observed between rotting and presence of lignin (patchy lignification or complete lignification). Instead, the completeness of the lignified layer was also significantly associated (($\chi^2 = 6.71$; $P = 0.010$; $\chi^2 = 25.33$; $P < 0.001$). This association was also stronger at day 6 than at day 3. These findings confirm the

importance of lignification to prevent microbial attack. And it may also be concluded that it is important that lignification is continuous to function as an effective barrier against pathogens.

6.4.5 Lignification and the dry matter content

6.4.5.1 Cultivar differences in DM content and lignin index

Figures 6.7a-d present the regression analysis for dry matter content and lignin index. 16 cultivars were used. In all cases there was a negative correlation between dry matter and lignin index. The regression was highly significant in trial 9 and 13a (P = 0.005 and P = 0.008), and in trial 11 and 12a the regression was significant to 10% (P = 0.065, and P = 0.052).

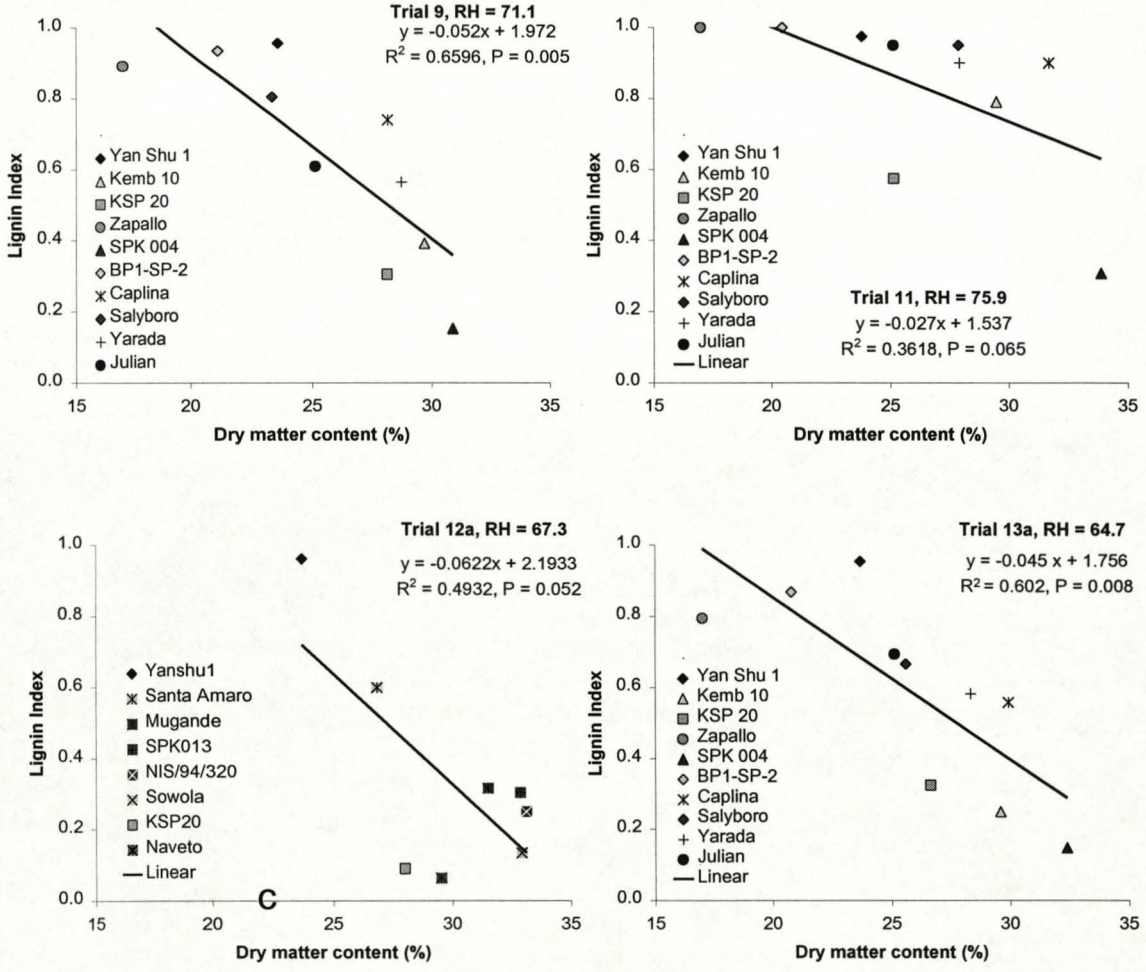


Figure 6.7 The relationship between cultivar DM content and the lignin index. Each point presents 1 cultivar.

According to the regression models the probability that wounds heal (lignin index) decreases with increasing dry matter content, and, on average, if the dry matter content increases by 1%, the lignin index decreases by approximately 0.05. This means that wounds in cultivars with a dry matter content of 28.6% have a probability of 0.5 of healing.

The dry matter content and lignin index were consistent for most cultivars, with Zapallo, Yan Shu 1 and BP1-SP-2 having a consistent high lignin index and low dry matter content, while the cultivars SPK 004 and Kemb 10 have a consistent high dry matter content and low lignin index. The significance of the relationship in trial 12a, with 'new' cultivars (Santa Amaro, Mugande, SPK 013, NIS/94/320, Sowola and Naveto) confirmed the relationship.

It was observed that the cultivar KSP 20 always showed a lower lignin index than would be predicted from the regression, while the cultivars Caplina and Yarada showed a higher lignin index than predicted. This indicates that the dry matter content is probably not the only factor determining the probability that lignification of wound occurs.

It was also observed that the regression model in trial 11 was less steep than in trial 9, 12a and 13a. This coincided with a higher relative humidity in trial 11, which was 75.9% as opposed to 71.1, 67.3 and 64.7% in the other trials. Although the difference in relative humidity did not affect the cultivars with a low dry matter content, it did affect the cultivars with a higher dry matter content. Possibly there is an interaction between the dry matter content of the cultivar and relative humidity necessary for wound healing.

6.4.5.2 The effect of relative humidity and DM on wound healing

Figure 6.8 presents the lignification indices of the cultivars during different curing conditions. The wound healing ability of sweet potato cultivars was tested at different levels of relative humidity: high 97%, intermediate 65% and low 58%.

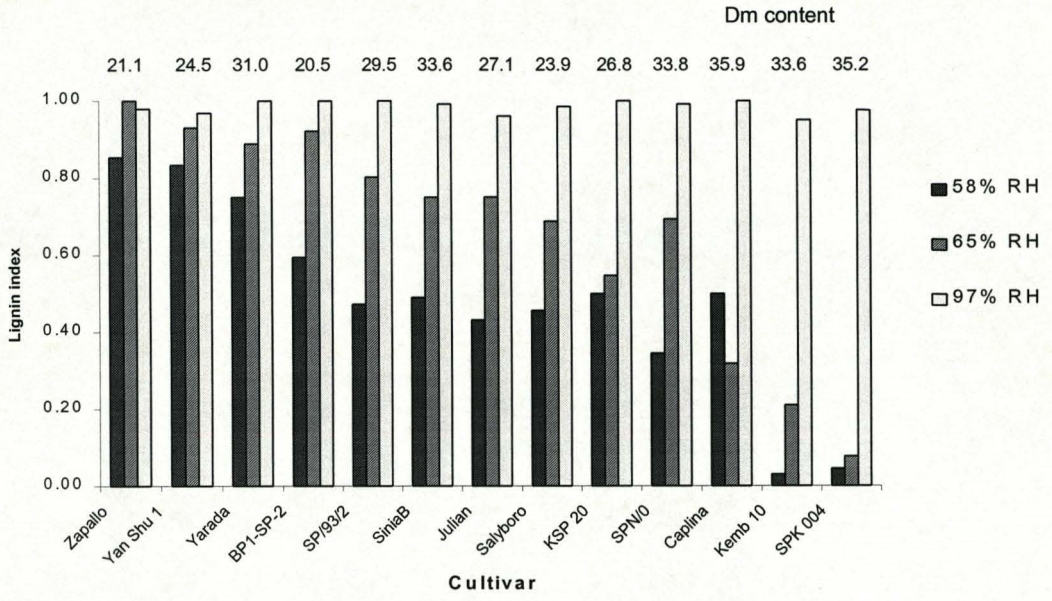


Figure 6.8 The lignin index of 13 sweet potato cultivars as stored under three different relative humidities.

At 97% RH all cultivars had a lignin index close to 1.0 including the cultivars with high dry matter content. This is in agreement with findings from Strider and McCombs (1958) who reported that under curing conditions there was no difference in the rate of wound phellem formation between dry and moist fleshed types.

At a lower RH the cultivars with a high dry matter content showed a low lignin index, while the lignin index of low dry matter content cultivars was high. Exceptions were observed for the cultivars Yarada, Sinia B, SP/93/2 which showed a relatively high DM content.

The interaction between lignin index, dry matter content and relative humidity suggests that the rate at which the tissue dries out might play a role in the wound healing ability. Possibly tissue with a high dry matter dries out too quickly. This might be associated with a critical moisture level in the tissue below which lignification can not occur. The rate of drying out, was comparable for high and low DM cultivars, which means that roots with a high DM content would have reached a critical moisture level more rapidly.

6.5 Summary and conclusions

6.5.1 *Summary of findings*

- Under tropical marketing conditions lignification of wounds does not always occur
- Lignification of wounds correlates with reduced susceptibility to weight loss, water loss and microbial attack.
- Sweet potato cultivars differ in the thickness of the desiccated cell they produce. The thickness is also affected by the relative humidity.
- A lignin index can be used as quick and simple method to estimate the probability that wound healing occurs
- The lignin index is specific for the relative humidity at which it is measured
- Cultivars differ significantly in their lignin indices. High Lignin indices were obtained for the cultivars Yan Shu 1 and Zapallo, while the cultivars SPK 004 and Kemb 10 showed a consistently low lignin index.
- A high dry matter content in cultivars correlated with a low lignin index. This relationship was consistent for 16 cultivars tested.
- There were however some outliers (KSP 20) which indicates that other factors should also be involved in the lignin index.

6.5.2 *Conclusion*

- Wound healing ability is a major factor for the shelf-life of sweet potato cultivars.
- Under sub-optimal conditions not all roots and cultivars are able to heal wounds.
- The DM content be crucial for storability of sweet potatoes, since a high dry matter content is related to poor wound healing ability.

Chapter 7

Sensory properties and storage

7.1 Introduction

Among the factors that could potentially limit the shelf-life of sweet potato, the eating quality is important to consider. Changes in sensory characteristics during storage which could make the roots no longer acceptable to the consumer could be limitation to shelf-life, even though the root has not deteriorated biologically, i.e. it is still functioning metabolically. As sweet potato is mainly used as a food in East Africa, changes in taste could affect the acceptability of stored roots to the consumer.

The objectives of the experiments described in this chapter were to find out whether changes in sensory properties could be a limiting factor for sweet potato storability. Firstly, the profiles of five sweet potato cultivars grown in East Africa were identified. Then it was investigated how these sensory characteristics change during storage.

7.2 Literature review

7.2.1 Consumer preferences for fresh sweet potato

Preferences for eating quality may vary widely according to the demographic and cultural background of the consumers (Shewfelt, 1999) and this is very notable in the case of sweet potatoes. Consumers in Bangladesh prefer cultivars with white flesh and red skin while consumers in the US like orange flesh and copper skin varieties (Hossain and Sidique, 1986; S-101 Technical Committee, 1980). The Consumers in the US prefer a moist mouthfeel, with intense flavour (S-101 Technical Committee, 1980) while in West Africa preferences exist for non sweet roots with moist mouthfeel (Almazan and Hahn, 1987; IITA, 1981). A sweet dry taste is preferred in the Phillipnes, while Puerto Rican farmers prefer dry and bland tasting roots (Martin and Rodríguez-Sosa, 1985). Tanzanian farmers prefer roots with white flesh, as they perceive that white flesh is a good indicator of high starch (Kapinga *et al.,* 1997b). Table 7.1 summarises the results of a survey in the Lake Zone of Tanzania upon urban consumers. They were asked to list the criteria which they considered most important, and asked to rank a list of criteria presented to them. Flouriness/starchiness and 'good taste' were the most important characteristics. Good taste may refer to various attributes, including sweetness (Kapinga *et al.,* 1997a).

Table 7.1 Characteristics of sweet potato roots preferred by urban consumers in the Lake Zone in Tanzania.

Characteristic	Percentage of consumers that find these characteristics important	Mean ranking of the characteristic by urban consumers (1=most important)
Starchy/floury	67%	1.5
Good taste	76%	1.9
Good cooking qualities (soft when cooked)	27%	2.7
Non/less fibrous	13%	2.9
Good storability	7%	3.0
Good root appearance (shape, size, colour)	15%	4.1

** Data sourced from Kapinga et al., (1997a)*

7.2.2 Changes of sensory properties during storage

The taste of fresh produce might change during storage. Storage of sweet potatoes could improve the quality of sweet potato. Freshly harvested roots have firm and dry texture but develop a soft, moist and desirable texture after curing and during storage (S-101 Technical Committee, 1980). Hamann *et al.,* (1980) reported that a sweet taste and moist texture are developed during curing. This is related to the starch breakdown which was higher during curing conditions than during storage conditions (Walter and Hoover, 1984).

However, storage can also affect the taste in a negative way. Studies in Sierra Leone revealed that some sweet potato cultivars developed an undesirable taste during storage, which became apparent after frying (George and Kamara, 1985). Also the development of internal brown spot during storage may result in a bitter taste (Miyazaki and Ino, 1991).

7.2.3 Sensory properties in relation to physiological characteristics

Textural properties such as 'moistness' or 'dryness' are complex organoleptic sensations. A moist mouthfeel does not necessarily relate to the dry matter or starch content of the raw product, but is probably related to the activity of amylolytic enzymes during the cooking process (Rao *et al.,* 1975a;1975b; Walter and Hoover, 1984, Martin, 1987). Dry flavour was found to correlate with the starch content remaining after cooking (Shen and Sterling, 1981, Walter *et al.,* 1975). The mealiness in potato was not related to the tubers specific gravity, which is a measure for dry matter content. Nor was the texture explained by the physico-chemical characteristics of the starch (McComber *et al.,* 1988). Van Marle (1997) observed that mealiness relates to the degree of cell separation after fractionating and the resistance to rupturing of the cell walls during cooking. McComber *et al.*, (1994) found that mealiness was associated with more polarized cell walls and with larger and more irregular shaped cells, engorged with gelatinized starch after cooking.

7.2.4 Sensory evaluation

So far the variation in sensory characteristics can not be fully explained by measurements of physico-chemical properties only. Therefore, the best way to assess eating quality is to use taste panels.

Different methods of sensory measurements can be distinguished. 'Consumer Preference and Acceptability tests' measure how consumers like, prefer or accept a product, and is often used to predict sales. 'Sensory Evaluation' aims to measure characteristics of foods by using humans. The results are quantitative rather than qualitative (O'Mahony, 1995).

According to O'Mahony (1995) there can be two types of sensory evaluation. *Sensory Evaluation I* relies on extremely sensitive and well trained humans, who can detect the slightest changes. *Sensory Evaluation II* uses normal consumers to measure the consumer perception of a food.

Food can be profiled using Quantitative Descriptive Analysis, which gives a broad analysis in terms of intensities of a set of sensory attributes. The attributes are normally generated in brainstorming sessions, followed by discussions of the panellists (Stone *et al.,* 1974). The intensity of the attributes can be scored on line scales. This technique renders the data comparative rather than absolute (O'Mahony, 1995). In this Chapter Qualitative Descriptive Analysis was used to detect changes in the taste of sweet potatoes during storage.

7.3 Materials and methods

7.3.1 Materials

Sensory evaluation was carried out upon the sweet potato roots from trials 1 and 2 and thus included five cultivars. The roots from trial 1 were used to generate descriptiors, and the roots from trial 2 were used to assess profiles during storage. The dry matter content of each cultivar was determined by weighing approximately 40 g of finely chopped tissue without periderm, which was then dried for 48 h in an oven at 80°C and re-weighed.

7.3.1.1 Storage

The sweet potato roots were stored under simulated tropical storage conditions in CT-rooms at 26°C. The roots were piled on racks suspended above a layer of water, through which air was bubbled providing ventilation and a relative humidity of approximately 80% RH. A detailed description of the storage set-up is given in Chapter 2, section 4.1).

7.3.1.2 Preparation of cooked samples

Sweet potato roots were chosen randomly from the stored piles, peeled and cut into equally sized pieces (20 mm thick). The pieces were steamed (100°C) for 20 minutes in pans (diameter 240 mm) above tap-water. Pieces of sweet potato were presented to the panellists on white round plates (Plate 7.1), and each piece of root was labelled with a random number selected from a table of random numbers.

7.3.2 Generation of descriptors and selection of panellists: phase 1

Volunteers from NRI were sought through e-mail advertising. 'Brainstorming' sessions were run for 4 separate groups, each with 6 to 10 tasters. The availability and motivation of potential panellists to participate in sensory evaluation were checked using a questionnaire Tomlins, see Appendix 4). Each taster individually generated a set of descriptors, for the appearance, the texture and the flavour of three contrasting cultivars: Kemb 10, KSP 20 and Zapallo. During subsequent discussions a consensus vocabulary was derived for each group.

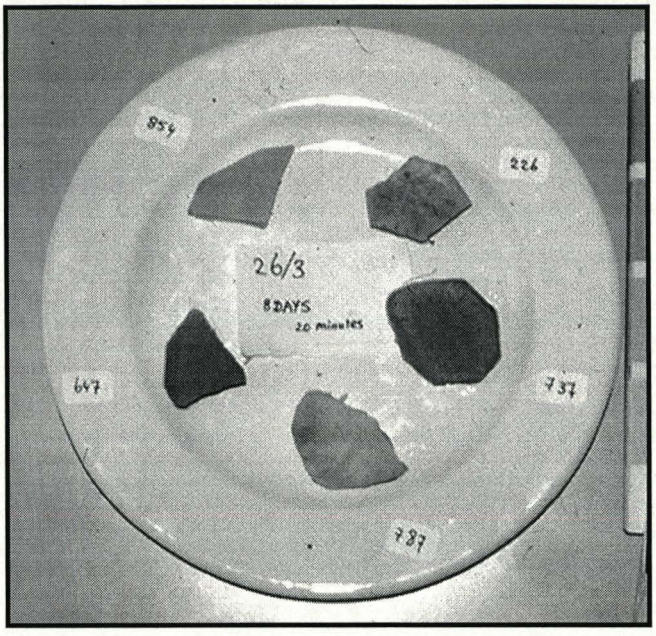


Plate 7.1 Plate of sweet potato pieces as presented to the panellists during sensory evaluation.

Later, mind mapping techniques (Buzan and Buzan, 1995) were applied to relate the terms generated with the preferred characteristics of Tanzanian consumers. In this way it was possible to identify relationships and links between characteristics.

After brainstorming, the tasters quantified the intensity of the characteristics chosen for the consensus vocabulary for freshly cooked samples of the three cultivars. Line scales were used for the scoring and each sample was scored on a separate form (appendix 5). The performance of each panellist was expressed in terms of the correlation coefficient of that panellists' score with the mean score of the whole group. Panellists were selected for participation in later sensory evaluation on the basis of performance and availability (good performance = high correlation coefficient).

7.3.3 Sensory evaluation during storage: phase 2

Sensory Evaluation was of the type of '*Sensory Evaluation II*' as described by O'Mahony (1995) which measures how consumers perceive the product.

7.3.3.1 Experimental design

Sensory evaluation was carried out upon 5 sweet potato cultivars at 1, 4 and 8 weeks of storage. Four tasting sessions were organised per storage time, and each of the thirteen panellists tasted all the cultivars at every session.

7.3.3.2 Quantitative Descriptive Analysis

Quantitative descriptive analysis, based on the method by Stone *et al.,* (1974). Intensity ratings were scored on a 15 cm linear unstructured scale anchored with the descriptors on either side (e.g *not floury* on the left side and *very floury* at the right side, Appendix 6). The panellists received a clear explanation of the scoring system, but no extensive training. The tasting sessions took place in the sensory evaluation lab at NRI.

7.3.3.3 Statistical analysis

A multivariate analysis of variance was performed in order to determine significant differences between sweet potato cultivars in sensory profiles. The model included panellist as blocking factor, and the factors cultivar, storage time and cultivar*storage time as main effects. One way analyses of variance were performed in order to determine the effect of storage time on each individual cultivar and attribute.

Because of the multi-dimensional character of the data set (each descriptor provides a dimension) and the numerous interrelationships between the descriptors, a dimension reducing analysis technique was needed to analyse the data set (Krzanowski, 1988). Accordingly Principal Component Analysis (PCA) was used. The purpose of PCA is to transform the set of original correlated descriptors into a new set of principle components, which are linear combinations of the original descriptors, and which are not correlated with each other (Digby *et al.,* 1989). PCA was carried out in Genstat using the mean of the 4 scores per panellist at each storage time. The relationships between the principal components, the descriptors and the dry matter content were determined using correlation coefficients. For the attributes and Principal Component 1 and 2 (PC1 and PC2), 195 data were used, while the correlations with the DM content were carried out with the mean dry matter contents per cultivar (5 data for 5 cultivars).

7.4 Results and discussion

7.4.1 Phase I: Generation of descriptors and panel selection

7.4.1.1 Generation of descriptors

Group discussions

The tasters generated 95 different terms to describe sweet potato. In Table 7.2 the most frequently used descriptors are presented along with the number of times they were used by the panellists. Sweet was used 58 times, while descriptors such as *soft*, *firm*, *smooth* and *hard* were used more than 20 times. In the next column of Table 7.2 the number of groups that chose each term as consensus vocabulary is shown. Thus s*weet, firm* and *a chestnutty flavour* were chosen by all (4) brainstorming groups. S*mooth, grainy* and *moist* were chosen by three groups and *floury, grey* and *fibrous* by two groups. S*oft, sticky, discoloration, fibrous appearance, flavour, sour* and *mottled* were only chosen by one group.

Categorising the descriptors

Figure 7.1 presents a mind-map of all descriptors generated during brainstorming. The mind-mapping technique permits an overview of relationships and links between the characteristics to be easily obtained. The terms were categorised as described below taking into account the attributes that Tanzanian households find important (Kapinga *et al.*, 1997a).

Texture attributes

Textural properties *starchy/floury,* were found to be important by 67% of the Tanzanian households. As shown on the mind map this characteristic corresponds with *grainy* or *dryness* and it could be considered to be the opposite of *moistness*. Hence *floury*, *grainy* and *moist* were chosen as being important for the profile. S*oftness* was regarded as important by 27% of the Tanzanian households and would be the opposite of *firmness* which was chosen by all 4 groups at NRI. According to the NRI panellists *smooth* and

soft were distinct characteristics and thus both were adopted in the profile. A *low fibre content*, which 13% of Tanzanians find important, was represented by *fibrousness* (in texture).

Table 7.2 Descriptors generated during brainstorming on the texture, taste and appearance of sweet potato. Column 2 and 5 present the number of times an attribute was used by panellists and column 3 and 6 present the number of times it was chosen after group discussions.

Descriptor	No. of times used during brainstorming	Descriptors chosen during the group discussion [2)]	Descriptor	No. of times used during brainstorming	Descriptors chosen during the group discussion [2)]
Sweet	58	* * * *	streaks/veiny	10	-
Soft	34	*	nutty	10	-
Firm	26	* * * *	appetizing/ unappetizing	10	-
Smooth	23	* * *	creamy	8	-
Hard	22	-	moist	8	* * *
Gritty	15	-	chewy	8	-
Floury	15	* *	orange app.	8	-
Blandness/dull	15	-	discoloration	7	*
Dry	14	-	taste good/bad	7	-
Chestnutty	13	* * * *	fibrous appearance	6	*
Sticky	12	*	lumpy	6	-
grainy	12	* * *	watery	5	-
dirty	12	-	uniform colour/blutchy	5	-
grey	12	* *	flavour/aroma	5	*
appealing	11	-	carrot flavour	5	-
crunchy	11	-	mottled	5	*
fibrous texture	11	* *	sour	2	*

[2)] *Each * presents a group consensus for the importance of the descriptor.*

Taste attributes

The taste characteristics *sweet/tasty* were found to be important by 76% of the households. It is difficult to interpret what Tanzanians understand by *tasty* since the word for *'tasty'* in Swahili is the same as for *sweet*. 13 of the 32 tasters used the word *chestnutty* to describe the flavour of sweet potato, and 10 tasters described sweet potato as *nutty*. Nuttiness has been associated with sweet potato in Puerto Rico (Martin, 1987) and since few other references exist to describe the typical sweet potato flavour (S-101 Technical Committee, 1980) *chestnutty* was considered as a useful descriptor.

Appearance attributes

For appearance *good root flesh colour* was regarded as important by 15% of the Tanzanian households. 'Good' is difficult to interpret and could either refer to lack of 'discoloration' or to the actual 'flesh colour'. It was decided to monitor the *discoloration* in this study.

Processing attributes

Good for processing means for the Tanzanians that the sweet potatoes are easily chipped and dried in the sun (Dr R. Kapinga, personal communication). Since this is not a sensory property, but a characteristic of the raw product, it could not be considered during the sensory evaluation.

Some terms (Figure 7.1) were difficult to categorise since they were focused on qualitative descriptions (*horrible, dirty, subtle, palatable)*. Other descriptions were based on comparisons with other foods (*raw octopus*, *warm cheddar, chestnutty, swede*)

Thus, the set of attributes finally selected was as follows: *floury, smooth, soft, chestnutty, sweet, fibrous, grainy, moist* and *discoloration.* The term firm was not adopted as it was assumed that firm is the opposite of soft.

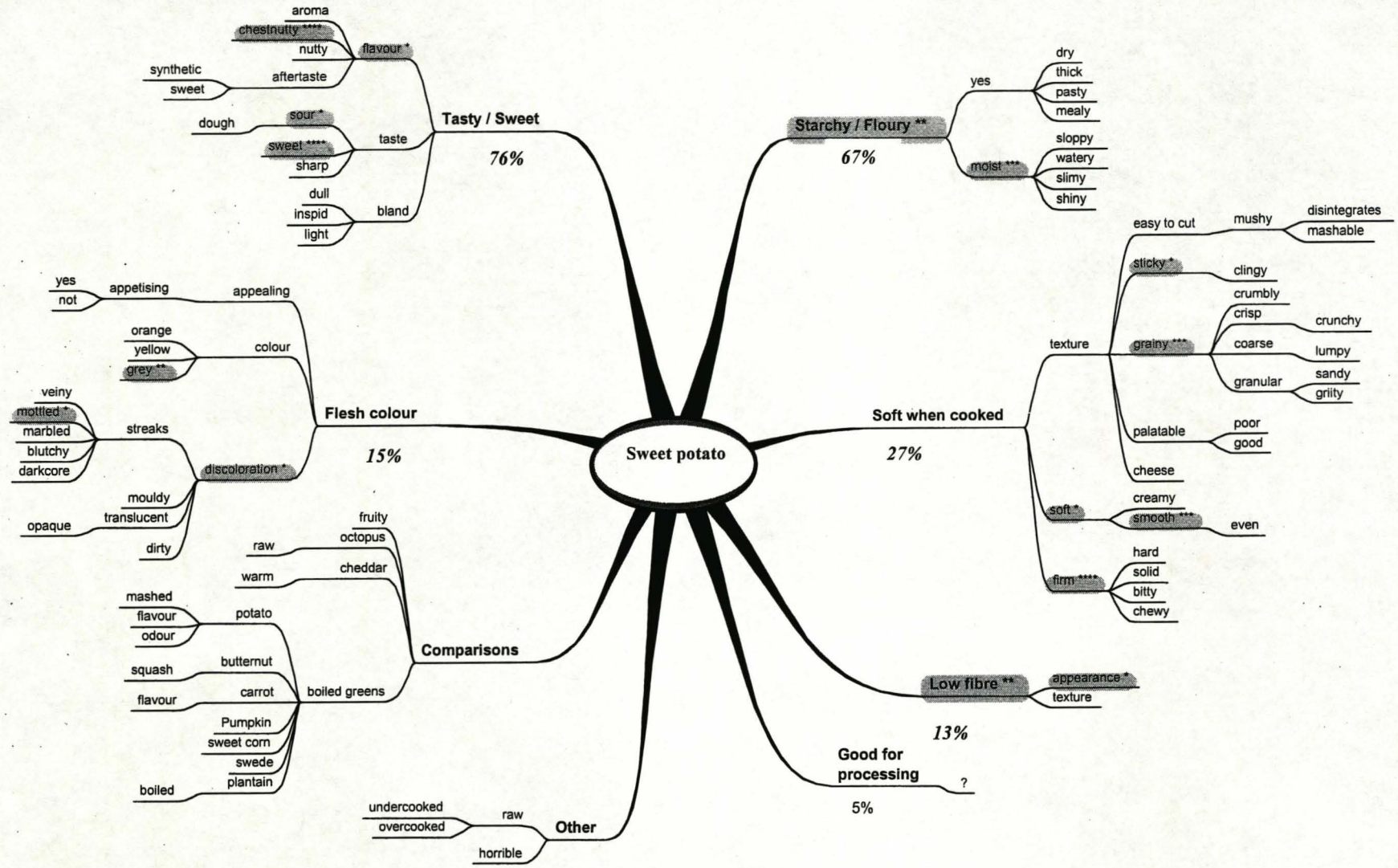


Figure 7.1 **Mindmap of all descriptors on sweet potato generated in four brainstorming sessions. The percentages refer to the percentages of Tanzania consumers that find the characteristics important (also Table 3.1). Each * refers to a group consensus for the importance of the descriptor (also Table 3.2)**

7.4.1.2 Selection of the panellists

Table 7.3 gives the results of the individual panellists during brainstorming sessions and the correlation of their scores in comparison to the mean value during preliminary taste tests. Most panellists (72%) had generated between 10 and 20 descriptors. The panellists number 26 and 32 had extremely low correlation coefficients (0.22 and 0.19) and were excluded from tasting sessions. Panellist number 25 had generated only 4 descriptors and was excluded. Further selection depended on availability which was assessed with a questionnaire. Thus a panel of 13 members was constituted.

Table 7.3 Number of descriptors generated by 32 panellists during brainstorming on sweet potato taste, texture and appearance, and the correlation coefficients during preliminary taste tests.

Panellist number	Number of terms the panellists described sweet potatoes[1)]	Correlation coefficient with the mean[2)]	Panellist number	Number of terms the panellists described sweet potatoes[1)]	Correlation coefficient with the mean[2)]
1	9	0.91	**17**	15	0.43
2	31	0.87	**18**	15	0.73
3	11	0.73	**19**	21	0.74
4	13	0.92	**20**	14	0.80
5	22	0.78	**21**	27	0.84
6	18	0.53	**22**	20	0.69
7	15	0.47	**23**	13	0.67
8	12	0.62	**24**	10	0.67
9	15	0.54	**25**	4	0.78
10	17	0.82	**26**	19	0.22
11	15	0.62	**27**	12	0.82
12	18	0.85	**28**	34	0.71
13	15	0.88	**29**	11	0.78
14	12	0.69	**30**	18	0.50
15	16	0.67	**31**	15	0.71
16	22	0.70	**32**	9	0.19

[1)] *The number of terms which was used on the brainstorming forms*

[2)] *The correlation coefficient with the mean of the scores during preliminary taste tests*

7.4.2 Phase 2: Quantitative Descriptive Analysis

7.4.2.1 Sensory profiles of 5 cultivars

There were significant differences in the initial profiles of the 5 sweet potato cultivars in the first week after harvest. A spider diagram of all cultivars after one week of storage is

presented in Figure 7.2. For each descriptor significant differences were observed among the cultivars (P = 0.002 for fibrous and P < 0.001 for all other descriptors). The range in smoothness, softness and moistness was large, while the range for *chestnutty*, *fibrous*, *sweet* and *grainy* was much smaller.

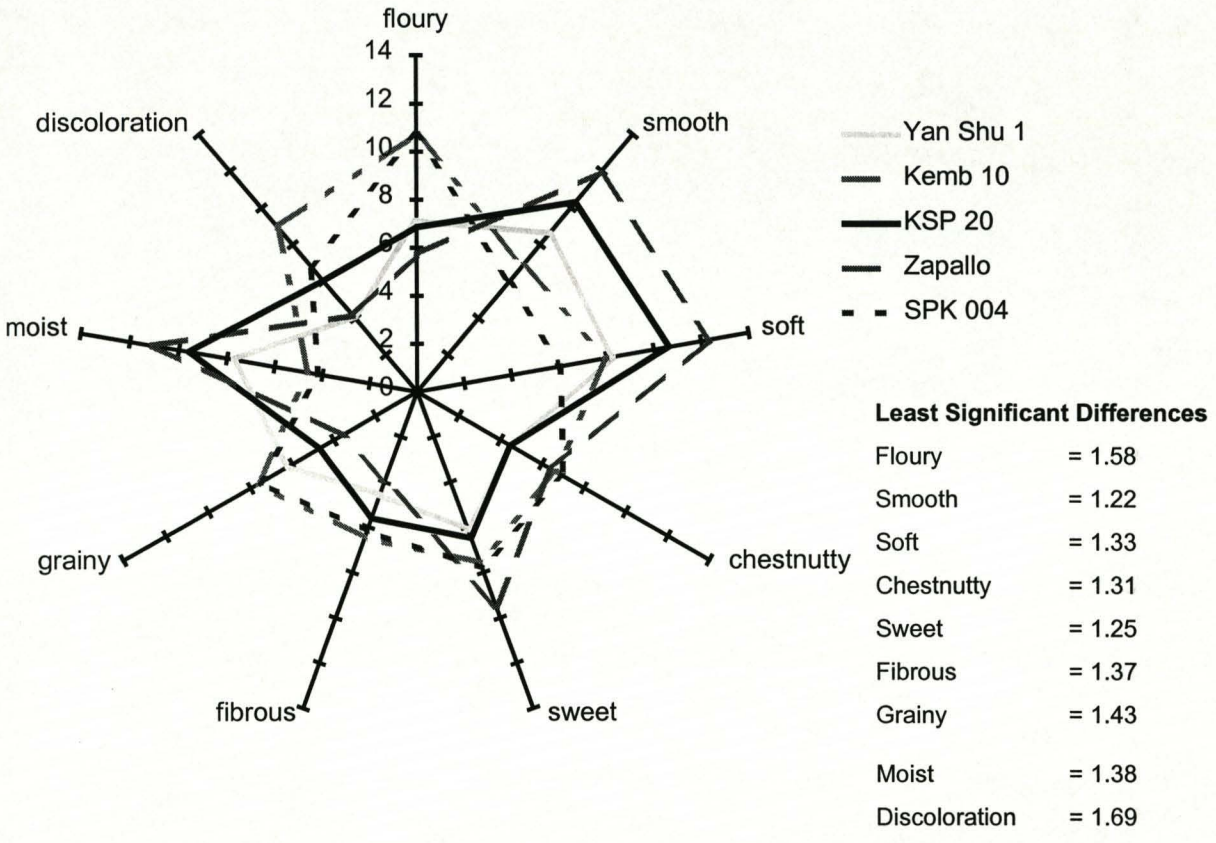


Figure 7.2 Sensory profiles for 5 sweet potato cultivars at 1 week after harvest presented as a spider diagram For all descriptors cultivars were significantly different at the < 0.001 level, except for fibrousness P = 0.002.

7.4.2.2 Sensory profiles during storage

Figure 7.3a-e presents the profiles of each cultivar after storage for 1, 4 and 8 weeks. It can be seen that the character of the profiles does not change greatly during storage.

Table 7.4 presents the overall effects of cultivar, storage time and the interaction between the two. Regardless of storage time, significant differences remain among the cultivars for each attribute (P< 0.001). Regardless of cultivar, storage did not have a significant effect on the attributes except for fibrousness, with the roots becoming more *fibrous*

during storage. The interaction between storage time and cultivar was however significant for the attributes *sweet*, *smooth*, *soft*, *grainy* and *moist* indicating that for these attributes these cultivars respond in a different way to storage.

Table 7.4 The effect of cultivar and storage time on the intensity of 9 sensory attributes. Sensory scores were obtained from 13 panellists who tasted each sample 4 times. Cultivars: Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, and storage times: 1, 4 and 8 weeks.

	Factor		
	Cultivar	**Storage**	**Storage * Cultivar**
Floury	< 0.001	0.943	0.823
Smooth	< 0.001	0.692	< 0.001
Soft	< 0.001	0.789	< 0.001
Chestnutty	< 0.001	0.110	0.439
Sweetness	< 0.001	0.087	0.036
Fibrousness	< 0.001	0.039	0.672
Grainy	< 0.001	0.723	0.020
Moist	< 0.001	0.340	0.003
Discoloration	< 0.001	0.536	0.077

The main changes observed were as follows. Changes in texture were most pronounced for the cultivar Yan Shu 1 which became significantly smoother, softer and moister after 4 weeks storage ($P < 0.001$). The smoothness, softness and moistness were however reduced after 8 weeks. A similar pattern was found by Rao *et al.,* (1975a and b) who reported that the moist mouthfeel increased up to 25 to 40 days of storage and decreased afterwards. A significant increase in smoothness was also observed for the cultivar Zapallo ($P < 0.05$). SPK 004 became significantly less *soft* and *moist* during storage ($P < 0.01$). The cultivar KSP 20 did not undergo significant changes of its attributes.

The cultivars SPK 004 and Kemb 10 became less chestnutty after storage ($P < 0.05$) and also their sweetness decreased significantly. The sweetness for Yan Shu 1 increased during the first 4 weeks, and slightly decreased later. This coincides with findings of

Picha (1986) who found that the changes in the concentrations of sugar content during storage may vary, and that cultivars differ in the sugar composition. He reported that under curing conditions, which are similar to tropical conditions, the maltose content decreases, while sucrose, glucose and fructose tend to increase. Since sugars rank in sweetness as fructose>glucose> sucrose>maltose (Belitz and Grosch, 1987) the increase in sweetness is possibly due to the high sucrose and glucose content.

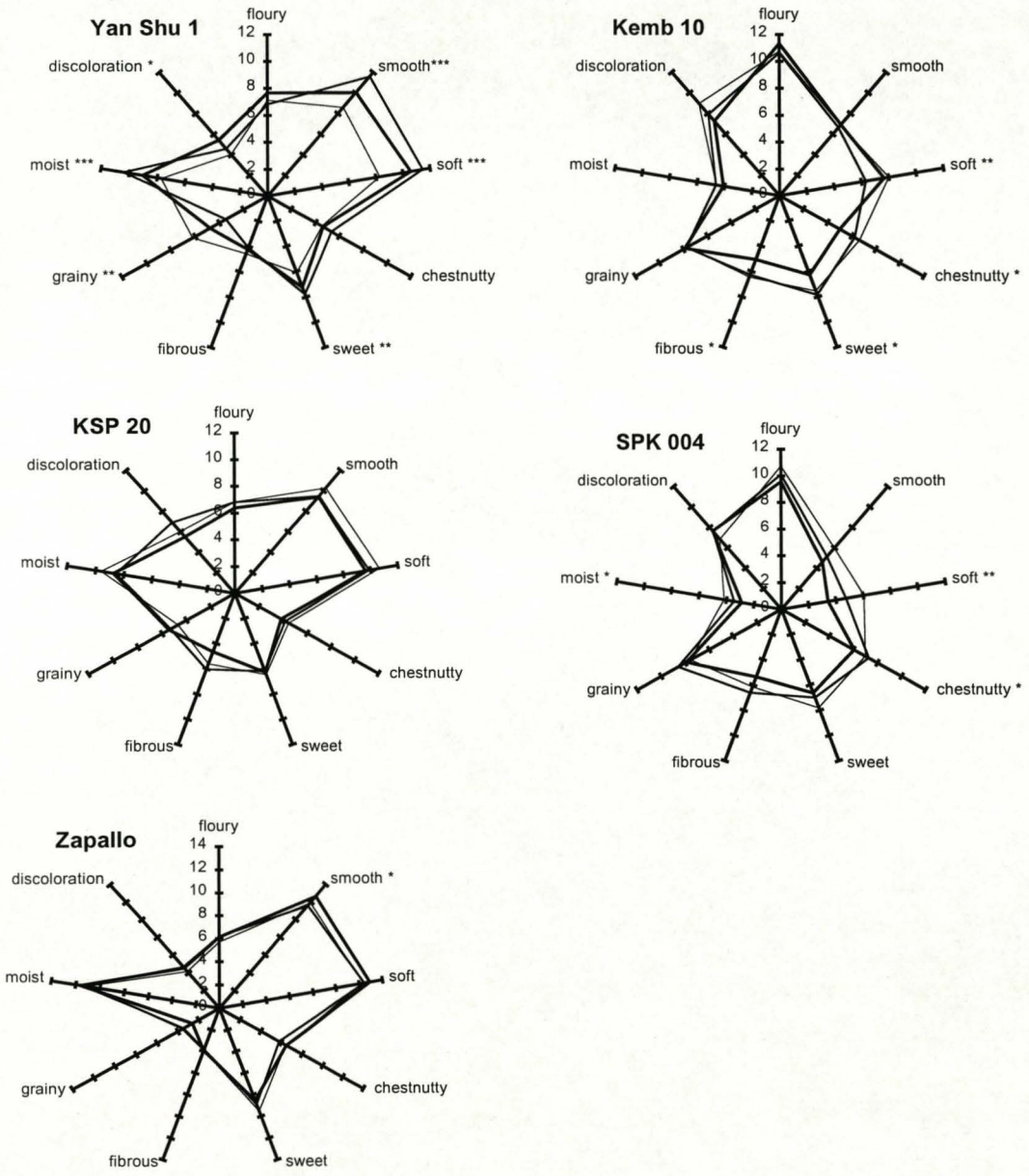


Figure 7.3 Sensory profiles presented as spider diagrams for 5 sweet potato cultivars during storage. —— = 1 week, —— = 4 weeks, —— = 8 weeks. The descriptors marked with *, ** or * differ significantly during storage at P < 0.001, P < 0.01 and P < 0.05 respectively**

It should however be taken into account that all conclusions drawn from this study are based on the assumption that the panellists are completely consistent during scoring and that all scores are objective. In reality sensory evaluation always contains some subjectivity because we rely on human for the measurements. In an ideal situation the comparison between stored and fresh sweet potatoes should be made simultaneously e.g. as a triangle test. However this was not possible for practical reasons.

7.4.3 Principal Components Analysis

Principal component analysis was applied to the combined set of the storage trials. The first two principal components explained 68% of the variation in the data and the first component alone accounted for more than 52% of the variation.

The attributes *floury* and *grainy* had high positive loadings for the first principal component and the descriptors *moist*, *smooth* and *soft* had high negative loadings (Figure 7.4). The second principal component had a high positive loading for the descriptor *chestnutty* and *sweet*.

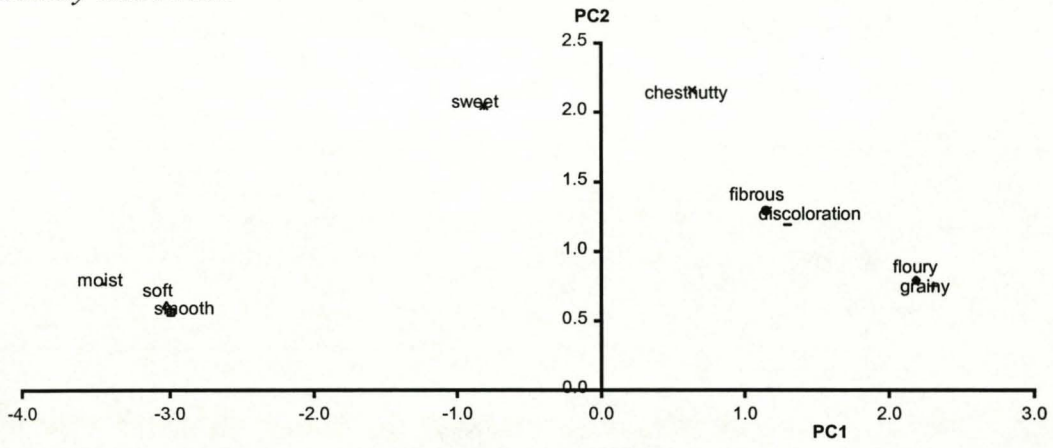


Figure 7.4 Principal component analysis (PCA) of sensory data for 5 sweet potato cultivars. Loadings (eigenvalues) for principal component (PC) 1 (52%) and 2 (16%).

Table 7.5 displays the initial DM contents of the cultivars before storage and the data were included in correlation analysis. The cultivars with high DM content also had high scores in flouriness (Figure 7.2 and 7.3).

Table 7.5 Dry matter contents of the five sweet potato cultivars on arrival in the UK.

	Dry matter content g/100 g fresh weight
SPK 004	38.6
Kemb10	33.4
KSP 20	29.3
Yan Shu 1	23.8
Zapallo	18.7

Table 7.5 presents the correlation coefficients between the principal components and original descriptors. It seems that PC1 gives information about texture and mouthfeel (*floury*, *smooth*, *soft*, *grainy*, *moist*) while PC2 presents the flavour components or the taste (*chestnutty*, *sweet*). The descriptors *floury* and *grainy* were highly correlated (0.936) as were *moist*, *smooth* and *soft* (>0.940). A strong correlation was also observed between the descriptors *fibrous* and *discoloration* (0.931).

Table 7.6 Table of correlations between the dry matter content, attributes and the principal components for 5 sweet potato cultivars.

	DM*	Floury	smooth	soft	Chest-nutty	sweet	fibrous	grainy	moist	Discol-oration	PC1	PC2
DM	1.000											
floury	-0.175	1.000										
smooth	0.040	-0.946	1.000									
soft	0.029	-0.855	0.975	1.000								
chestnut	-0.643	0.597	-0.407	-0.294	1.000							
sweet	-0.650	-0.094	0.311	0.394	0.738	1.000						
fibrous	-0.11	0.889	-0.803	-0.693	0.329	-0.295	1.000					
grainy	0.096	0.936	-0.987	-0.947	0.374	-0.341	0.789	1.000				
moist	0.059	-0.975	0.992	0.940	-0.492	0.222	-0.822	-0.987	1.000			
discolor	-0.073	0.852	-0.679	-0.507	0.481	-0.059	0.931	0.702	-0.742	1.000		
PC1	-0.047	0.971	-0.995	-0.948	0.442	-0.279	0.846	0.987	-0.997	0.747	1.000	
PC2	-0.571	0.436	-0.138	0.044	0.870	0.763	0.357	0.129	-0.251	0.596	0.212	1.000

**) correlation for five values (1 per cultivar) only, using the mean scores at week 1*
The level of shading correlates with the level of correlation i.e. the darker the shading the higher the correlation coefficient

Surprisingly the DM content characteristic did not correlate with flouriness or graininess in Table 7.5. The DM content was however found to be negatively correlated with *chestnutty*, *sweet* and PC2 (-0.643, -0.65 and –0.571 respectively) thus implying that these charateristics are low when the DM content is high. The DM content did not correlate with moistness. This confirms the findings of Martin and Rodrígues-Sosa (1985) that moist mouthfeel is not necessarily related to the moisture content of the raw root, but that the starch remaining after cooking and the activity of the amylotyic enzymes is most important (Walter *et al.,* 1975).

The scores for PC1 and PC2 of the five sweet potato cultivars with respect to storage time are presented in Figure 7.5. The distribution of the cultivars along the first principal component reflects the flouriness versus moist characteristics. Thus Zapallo presents a moist character, while SPK 004 and Kemb 10 present highly floury and grainy properties. For the second principal component, which relates best to sweetness and chestnutty flavour the cultivars Kemb 10, Zapallo and SPK 004 had the highest values. The low values for Yan Shu 1 and KSP 20 on PC2, indicated a rather bland taste. It was noticed that the principal components of Zapallo changed least during storage. For all other cultivars the changes were most pronounced for PC2. Decreases were observed for Kemb 10, KSP 20 and SPK 004, and Yan Shu 1 decreased in the first 4 weeks, then increased. For PC1 most cultivars remained relatively constant, except Yan Shu 1 for which PC1 increased during the first 4 weeks and decreased after 8 weeks.

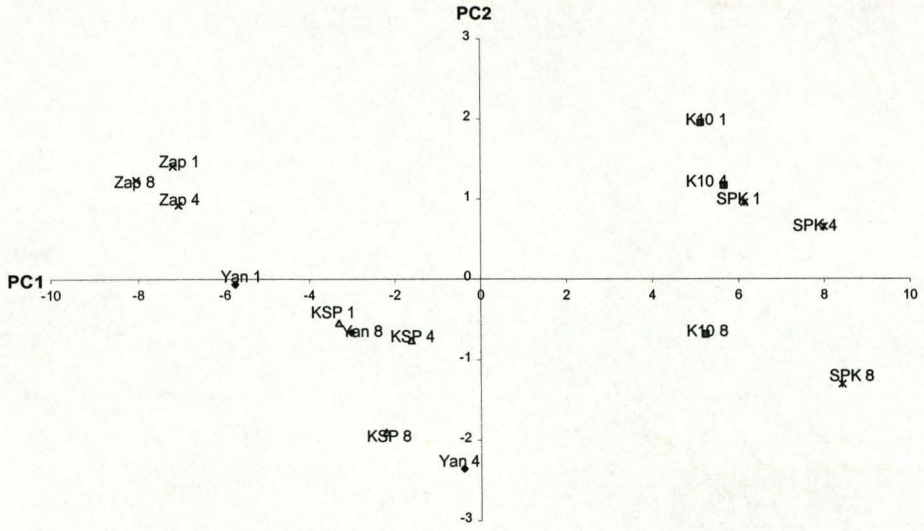


Figure 7.5 Sample scores of 5 sweet potato cultivars on the first and second principal component. (Zap = Zapallo, Yan = Yan Shu 1, KSP = KSP 20, K10 = Kemb 10, SPK = SPK 004). Each value is the mean of 13 panellists. The numbers refer to the storage time (1, 4 and 8 weeks).

Based on the changes as recorded during storage the following recommendations can be made. If a floury texture is most desirable (e.g. in the Lake Zone in Tanzania, Kapinga *et al.,* 1995) then cultivars such as SPK 004 and Kemb 10 are recommended. However, for consumers with preference for smooth and soft texture, the cultivars Zapallo, KSP 20 and Yan Shu 1 should be used.

If sweet potatoes with intense flavour are required (*chestnutty* and *sweet*), the cultivars Zapallo, Kemb 10 and SPK 004 should be recommended. However Kemb 10 and SPK 004 tend to lose their tastiness (PC1) after 8 weeks storage, and would only give the required properties up to 4 weeks storage. The cultivars Yan Shu 1 and KSP 20 would be recommended if a less intense taste is required.

7.5 Summary and conclusions

7.5.1 Summary of findings

- Nine descriptors were derived to characterise the profiles of 5 sweet potato cultivars. These were: *floury, smooth, soft, chestnutty, sweet, fibrous, grainy, moist* and *discoloration.*
- There were significant differences in sensory profiles among the cultivars. The cultivars Kemb10 and SPK004 were floury, dry, chestnutty, grainy, and not smooth and soft, while KSP20 and Yan Shu 1 were soft- and smooth, relatively moist, moderately floury but not sweet or chestnutty. Zapallo was characterised by moist, smooth, soft texture not floury, but sweet and moderately chestnutty.
- The 9 attributes could be reduced to two principal components explaining 68% of the variation of which the first principal component explained 52%. PC1 correlated with textural properties such as floury, grainy, and absence of moistness, smoothness and softness. The second principle component explained 16% of the variation and reflects the taste and flavour of sweet potato. PC2 correlated with chestnutty flavour and sweetness.
- Upon storage most of the cultivars tend to lose more of the sweet and chestnutty character, rather than the texture character. An exception was Yan Shu 1 which lost some of its moist character.

7.5.2 Conclusion

- Although storage affected some of the attributes, the changes during storage were less significant than the differences between the cultivars. Therefore, sensory changes are not a limiting factor in the storage under tropical conditions.

Chapter 8

General Discussion

The perishability of sweet potatoes in the tropics limits its potential as a staple crop. The research presented in this thesis investigates the role of a number of physiological factors upon the storability of sweet potatoes. The experiments were conducted under tropical marketing conditions, i.e. low or moderate relative humidity and therefore sub-optimal for storage.

Weight loss

It was established that weight loss is the most important factor that limits shelf-life under tropical marketing conditions. Furthermore a large range in weight loss exists among the sweet potato germplasm with weight losses ranging from 5 to 15% per week (3.4.1 and 3.4.3). This indicates that shelf-life can potentially be improved by cultivar selection. Among cultivars grown in Kenya, Yan Shu 1, KSP 20, BP1-SP-2 and Caplina showed good storability, while among the cultivars grown in Tanzania, Bilagala, Kagole and 440088 gave the lowest weight loss.

Weight loss is an important criterion as it appears to impact upon several symptoms of deterioration. Weight loss correlated with marketable appearance. Roots with a weight loss above 35% were regarded as unsaleable, while roots with a weight loss less than 20% were considered to be marketable (3.4.7). Weight loss was mainly caused by moisture loss and only about 10% was due to respiratory metabolism (3.4.2). It was found that roots that lose weight quickly also rot more rapidly, such that weight loss after 1 week correlated highly with scores of rotting after 3 weeks (3.4.5). It appears that the desiccation of the tissue affects the defence mechanisms of the tissue, which are therefore no longer able to effectively keep micro-organisms out, and rotting occurs. The stress due to desiccation resulted in an increase in respiration. Cultivars with good storability, exhibit a decreasing rate of water loss during storage, while the rate of water loss in poor storable cultivars remains high. Weight loss curves of poor storable cultivars hence have a more linear character (Fig 3.4). Further observations upon sprouting indicated that sprouting tends to occur mainly in roots with low rates of weight loss (3.4.6).

Wound healing

Lignin index

It has been established in this study that storability of sweet potatoes under marketing conditions is related to the ability of cultivars to heal wounds. Although it has been well documented that sweet potatoes heal wounds under ideal curing conditions, this was not found to be the case under tropical marketing conditions and some cultivars consistently failed to heal their wounds (6.4.1.3). Wound healing ability therefore seems to be cultivar related. It is suggested that the use of a lignin index is an effective way of measuring wound healing ability. The lignin index expresses the probability that wound healing occurs under the conditions tested. Lignification of wounds can be rapidly assessed using phloroglucinol/HCl which stains the lignin red and the wound sections can be assessed with the naked eye (6.3.4). The advantage of this method is that it can be easily adopted by breeders, and does not require costly equipment.

Although wound healing involves many processes in addition to lignification, the results presented in this research confirm that lignification correlates with effective wound healing that protects the underlying tissue against microbial invasion and water loss.

Thus significant associations were found between lignification and susceptibility to *Rhizopus oryzae* and lignification was also associated with reduced transpiration rates through wounds (6.4.3 and 6.4.4).

Lignification and dry matter

Cultivars with a low dry matter (DM) content showed consistently higher lignin indices than cultivars with a high DM content. This relationship was valid among the 16 cultivars assessed (6.4.5). So far no other reports have been found that describe this relationship and it contradicts the general expectation that a high DM content coincides with longer shelf-life. The relationship found in this research, implies that cultivars with a high DM content are less suitable for marketing than cultivars with a low DM content. The mechanism by which the DM content affects wound healing is not understood. It is possible that wound healing ability is directly related to the rate of desiccation of the tissue. Porometer readings indicate that tissue with a high DM content initially loses water at the same rate as tissue with a low DM content (6.4.3.1), and might therefore reach a critical level of moisture content more rapidly than tissue with a low DM content. The hypothesis would be that below a critical level of moisture content the tissue is too stressed, resulting in failure to form the protective lignified layer under the wound.

Desiccation of several outer cell layers of the wound occurs normally prior to lignification. The observations upon the thickness of the desiccated cell layer correspond with the above hypothesis. The desiccated tissue at the wound surface was thicker for roots with high DM content (Plate 6.2), and also in cases where wounded roots were stored at low relative humidity (58-65%; Plate 6.3). Tissue of unhealed wounds stained with safranin, which indicated the presence of phenolics. This indicates possibly that the healing mechanism was initiated but not completed.

The rate of desiccation may however not be the only factor affecting the wound healing ability since there were some consistent outliers; The cultivar KSP 20 healed less well than predicted from the DM/lignin index relationship, while Caplina and Yarada healed better than expected.

Potato versus sweet potato

Considerable differences were observed between wound-transpiration profiles of potato and sweet potato. The transpiration rate through potato wounds decreased rapidly after wounding, confirming the findings of Lulai *et al.,* (1996), while for sweet potato the transpiration rate decreased more slowly (6.4.3.1). This casts some light upon the differences in the nature of the barrier formed for potato and sweet potato. The barrier formed in potato stained positive with sudan III but not with phloroglucinol/HCl and is therefore assumed to consist mainly of suberin. The barrier in sweet potato stains bright red with phloroglucinol/HCl and slightly with Sudan III and is believed to be a ligno-suberin-like substance with more lignin character (McClure, 1960). The results in this thesis did not only confirm the differences in composition as measured by staining, but also emphasise that wound healing in potato is more efficient than sweet potato.

The rates of water loss found in potato and sweet potato followed the patterns of wound healing. In all cases potato showed much slower rate of weight loss than sweet potato. Wound healing efficiency is probably partly responsible for this relationship, although another factor that could contribute is the thickness of the periderm. While potato skin consists of 6 to 8 cell layers, sweet potato skin has only 2 to 4 layers (4.4.2). The findings in this thesis illustrate how difficult it is to compare sweet potato with potato. The differences probably lie in the fact that potato is a stem tuber while sweet potato is a storage root and thus originate from different parts of the plant. It may be more realistic for future research to compare sweet potato also with other roots such as carrots, yams or parsnips.

Susceptibility to damage

Handling and transport systems for sweet potatoes are poorly developed in Tanzania, and can lead to high levels of damage. It is thus important to consider cultivar variation in susceptibility to damage. Using standardised damage treatments it was found that cultivars differ in their susceptibility to damage (5.4.2). Different forms of damage were distinguished such as breaks, deep wounds, superficial damage and skinning injury. Water loss through damaged areas was found to be many times higher than through undamaged periderm (5.4.1.2).

Skinning injury

Although skinning injury does not affect the marketability of sweet potato in Tanzania (Tomlins *et al.,* 1999a) it increases weight loss and susceptibility to pathogens. Skinning injury correlated with weight loss for the first 5 days (5.4.1.1). After one week this form of damage became less important and it is assumed that wound healing of skinning injury has been completed after this time. In this research it was found that the susceptibility to skinning injury decreases with the thickness of the skin (5.4.4). This might be related to higher adhesion strengths for thicker skin.

Pruning or haulm killing before harvesting has been reported to reduce skinning injury in potatoes and thereby reduces water loss and increases shelf-life. The effect of pruning is related to the skin-set of the roots prior to harvesting. Skin-set occurs when the phellogen ceases to divide. In this research it was found that pruning plants 1 or 2 weeks before harvesting had a significant beneficial effect for one of the five cultivars, KSP 20, and both skinning injury and weight loss were significantly reduced (5.4.5).

Breakage

Breakage was found to be the most severe form of damage, having the greatest effect on weight loss. Even after 14 days of storage weight loss was still correlated with breakage (5.4.1.1). It is suspected that broken surface has a higher rate of water loss, even after healing, or that the surfaces only partially healed. Using standardised damage treatments it was found that cultivars differ in their susceptibility to breakage (5.4.2.2). The cultivars SPK 004 and Kemb 10 were most susceptible to breaks and Zapallo least susceptible. Furthermore, long shaped roots were more susceptible to breakage than oblong or ovate shaped roots (5.4.3). Since cultivars vary in their shapes, shape could be a criterion for cultivar selection.

Storability: The overall picture

Storability is a complex characteristic in sweet potato. It is a result of many physiological aspects, which among themselves may affect each other. In this study significant cultivar differences were found for each of the physiological aspects tested, all of which affected the storability in some way.

Table 8.1 presents an overview of the findings upon physiological characteristics for sweet potatoes. The cultivars are ranked in order of storability (weight loss). The ranking in weight loss relates well to the scores of wound healing. There are however two outliers in this relationship: KSP 20 and Caplina. These can be explained by their favourable shape (oblong; 4.4.1.2) and low susceptibility to damage (5.4.2.3). Further it is noted that the cultivars Kemb 10 and SPK 004 are least susceptible to skinning injury and have a low permeability through the periderm (4.4.3.1). However, because of their shape (long irregular; 4.4.1.2)), these cultivars are easily damaged, which with the poor wound healing ability results in poor storability.

Table 8.1 Overview of physiological factors affecting storability of sweet potato

		Damaged roots				Intact roots			
	Weight loss	Wound healing ability	DM	Susceptibility to breaks	Susceptibility to skinning injury	Periderm thickness	Permeability native periderm	Shape	Surface area/ mass ratio
Source	Fig 3.4	Fig 6.4	Fig 6.4	Table 5.6	Table 5.6	Fig 4.3	Fig 4.5	Fig 4.2	Fig 4.1
Yan Shu 1	○	○	○	●	◒	○	◒	●	●
KSP20	○	●	◒	◒	◒	○	○	○	◒
Caplina	○	◒	◒	○	◒	◒	◒	○	◒
BP1-SP2	○	○	○	○	●	◒	◒	◒	◒
Zapallo	◒	○	○	○	●	●	○	◒	○
Salyboro	◒	◒	◒	◒	◒	◒	◒	○	○
Yarada	●	◒	●	◒	◒	○	●	●	●
Julian	●	◒	◒	◒	●	●	●	◒	○
Kemb10	●	●	●	●	○	◒	○	●	◒
SPK 004	●	●	●	●	○	○	○	●	●

○ = favourable for storability

◒ = intermediate effect on storability

● = unfavourable for storability

SAFE, Cranfield University, Quirien van Oirschot, 2000

Sensory aspects

Sensory characteristics are obviously important for cultivar selection. The best way of assessing taste is still by using taste panels. In this research, expert taste panels were used to identify the sensory characteristics of sweet potato cultivars. The panellists generated 5 attributes to describe the texture and 2 for flavour (7.4.1). This possibly reflects the importance of textural characteristics as opposed to flavour and aroma. The profiles exhibited little changes in textural properties during storage (7.4.2.2), suggesting that sensory changes are not a limiting factor for the storage of roots.

Earlier in this discussion it was stated that low DM cultivars are best for storage. Since consumers in Tanzania tend to prefer sweet potatoes with the floury characteristics, which are usually found in high dry matter cultivars, the uptake of low DM cultivars could be difficult. However, consumer preferences are dynamic, and Low *et al.,* (1997) reported that the low DM cultivar Zapallo has good potential as it was found acceptable in taste tests in Kenya. Low DM cultivars could especially be suitable for infants who may find it easier to digest.

Recommendations for further research

Further research is necessary to better understand and improve the shelf-life of sweet potatoes. Areas of interest should include further selection of cultivars with good storability, a better understanding of the physiology of wound healing and the feasibility of long term storage.

Cultivar selection

- A broader range of cultivars should be screened for storability. This research has covered a total of 45 cultivars, which is just a minor percentage of the total germplasm available. Cultivars bred in other parts of the world, e.g. in the USA should also be included. This would enable us to identify outliers, for example cultivars with a high dry matter content and good wound healing properties. Screening should include assessment of wound healing using the lignin index.
- Promising cultivars such as Yan Shu 1, KSP 20, Caplina and BP1-SP-2 should be part of further studies e.g. for long term storage. Their acceptance should be tested for consumers, including consumers in urban areas.

Wound healing physiology

The hypothesis that desiccation in relation to the DM content affects the wound healing mechanisms deserves further attention. The following topics should be considered.

- A better understanding is needed of the water relations in tissue during desiccation. Research should include measurement of water activity and its relation to the activity of key enzymes in wound healing should be considered.
- The physiology of desiccation, lignification and wound periderm formation should be considered using histochemical analysis of the wound. Comparison should focus on physiological changes in other root crops such as yams, carrots and parsnips.

Long term storage of sweet potatoes

The storability of sweet potatoes during marketing in East Africa is effectively limited by the rate of water loss, which are due to poor conditions with low relative humidity. As demonstrated in this thesis, wound healing can occur for all cultivars under more conducive storage facilities if they are designed to enable curing. Although under different conditions other factors such as rotting may become limiting. Specifically designed stores could potentially facilitate long term storage.

- Specially designed stores, such as pits and clamps should be tested in specific areas where storage is not yet conducted. Its introduction should follow a participatory approach involving farmers in the design of the stores. It would be necessary to identify the critical factors in the design of the stores such as ventilation and the role of lining material.
- Techniques developed for other root crops such as cassava could be easily adapted for the purpose of sweet potatoes. These low technology storage techniques could include storage in plastic bags, and storage under plastic.
- As damage is the most important factor that affects storability of sweet potatoes, awareness should be raised for the importance of adequate handling. Whether this will be adopted depends on the economical viability. Socio-economic studies are needed to determine whether improved handling can benefit the farmer and traders.
- The economical feasibility of sweet potato storage is yet to be determined. Its success will depend on the willingness of the farmers and traders to take up this new approach.
- The marketability of stored roots should be determined. Tests for marketable appearance should be included after long term storage trials.

Final conclusions

The key factor of storability of sweet potatoes under tropical marketing conditions is water loss. The broad range in weight loss that exists among the germplasm indicates that there is considerable potential for increasing shelf-life. Selection of cultivars with good storability should be based on the following criteria:

- Cultivars should have low rates of weight loss during storage.
- Cultivars should have good wound healing ability, which is expected to be found in cultivars with a low dry matter content
- Oblong or obovate shaped cultivars are less susceptible to breakage and are therefore suitable for transport and marketing.
- Cultivars with a thick periderm are less susceptible to skinning injury, and these should be selected if transport over long distance is required.

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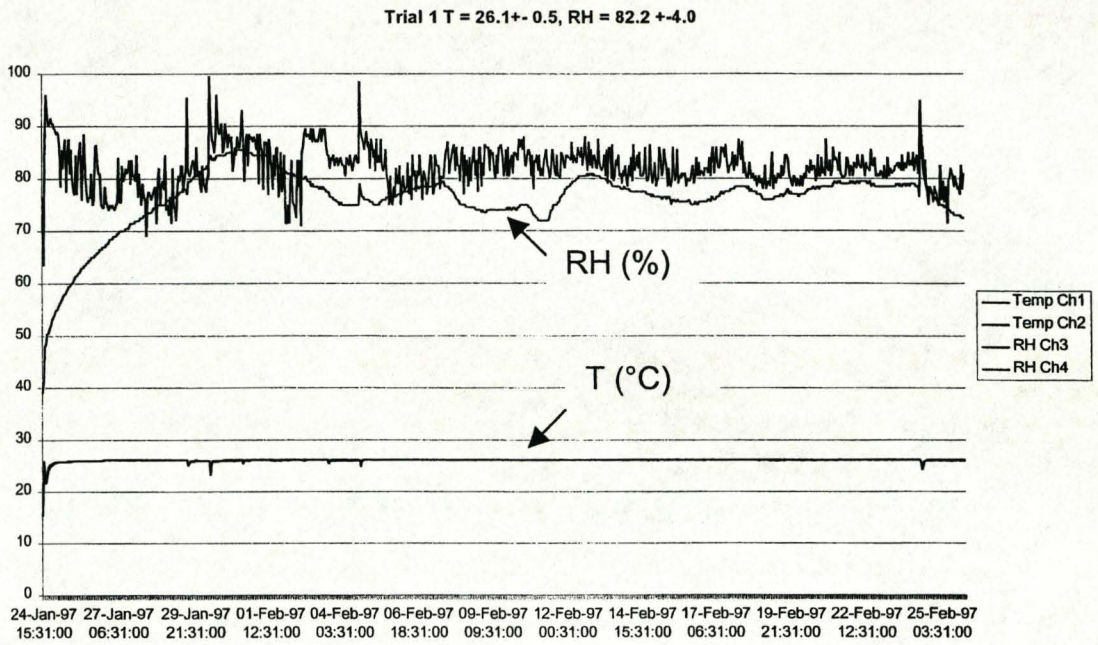
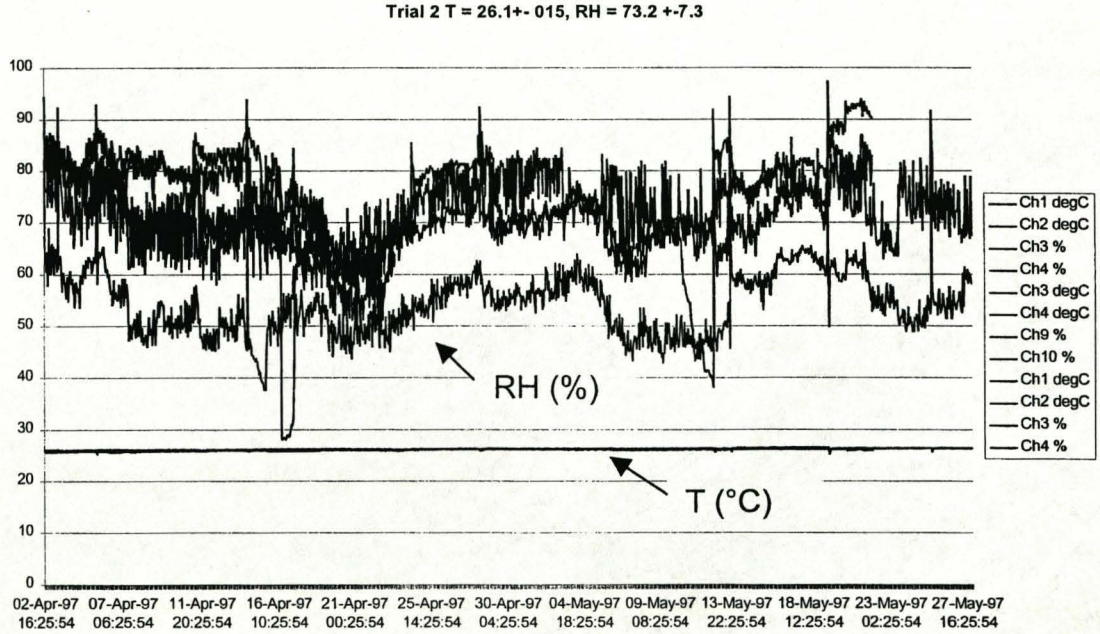
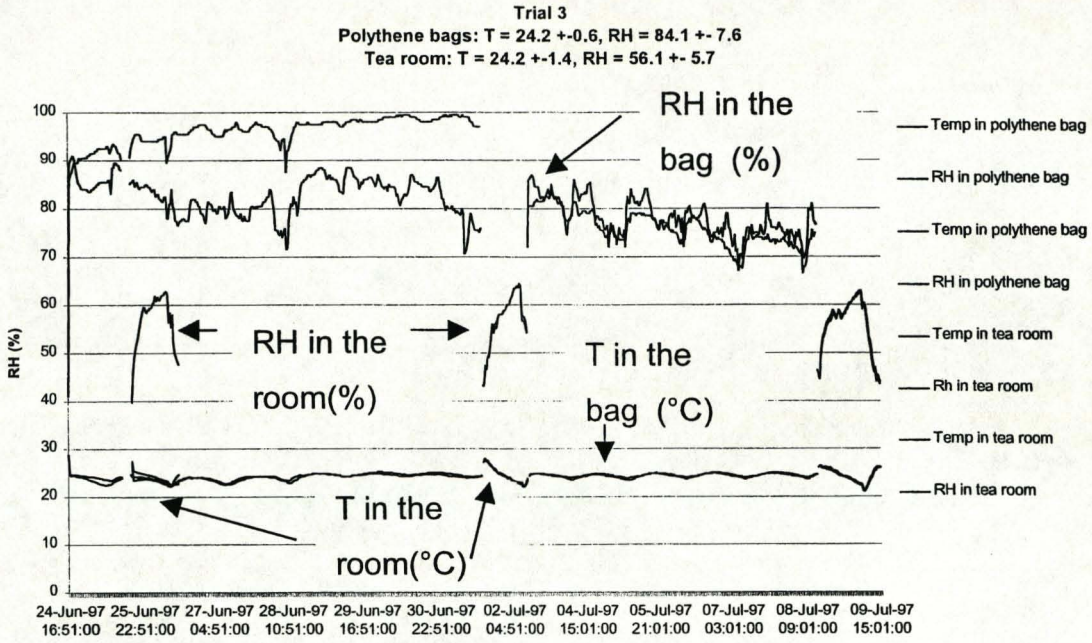
Appendix 1



Storage conditions during trial 1



Storage conditions during trial 2.



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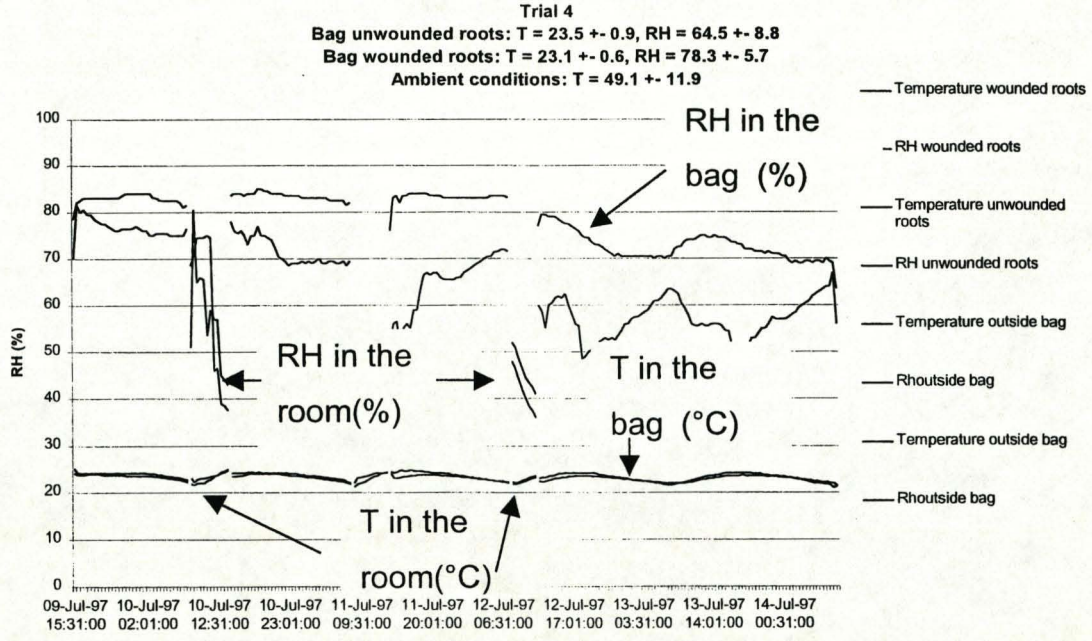

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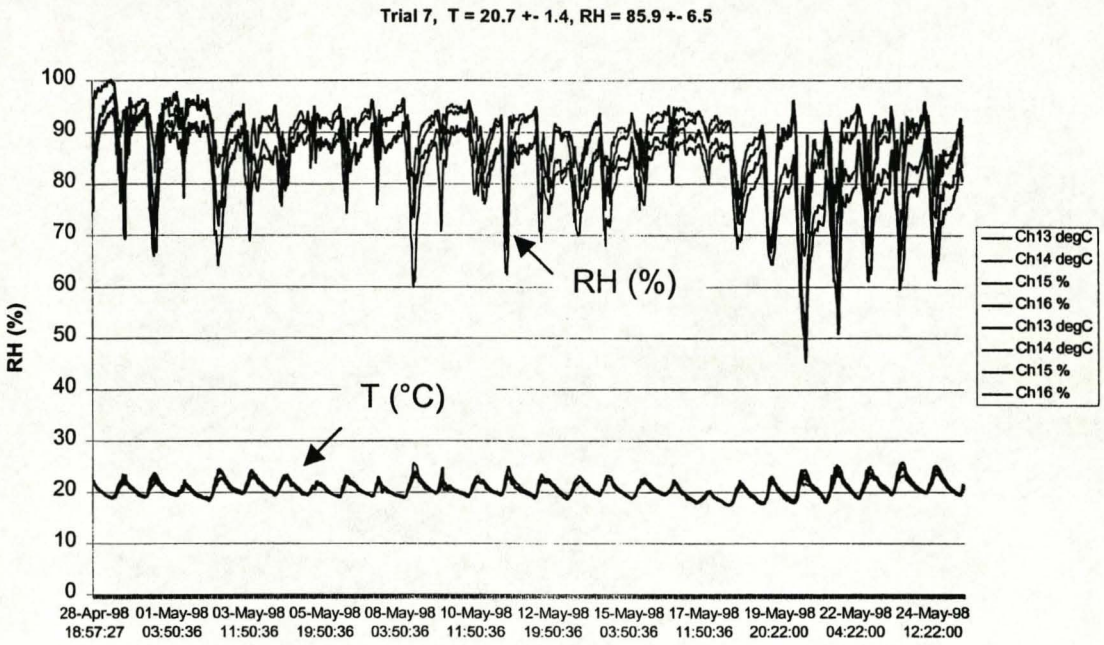

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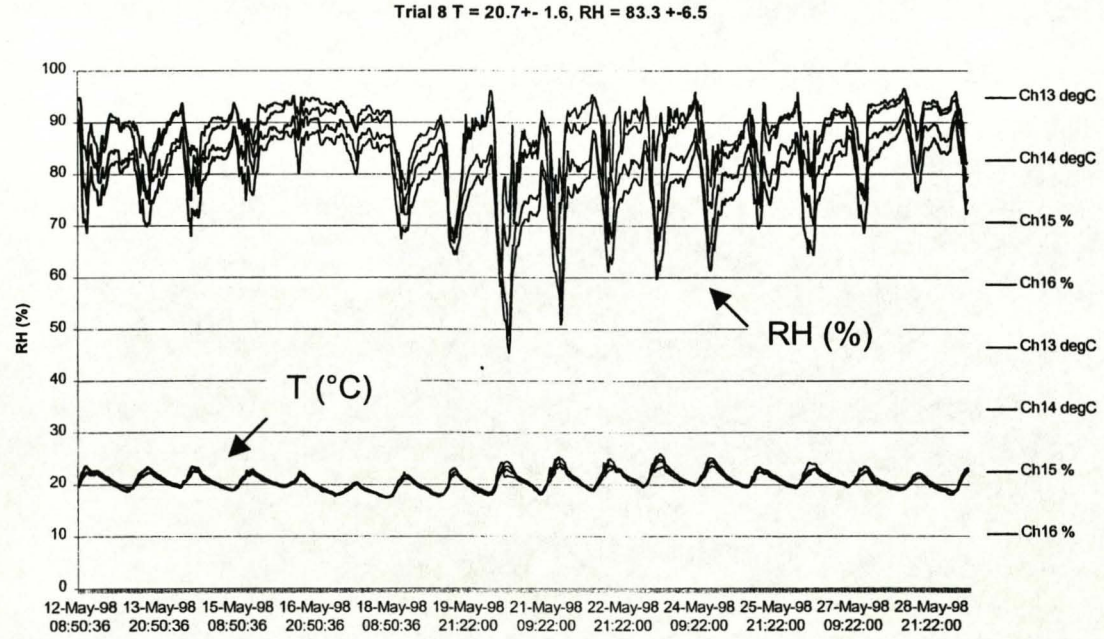

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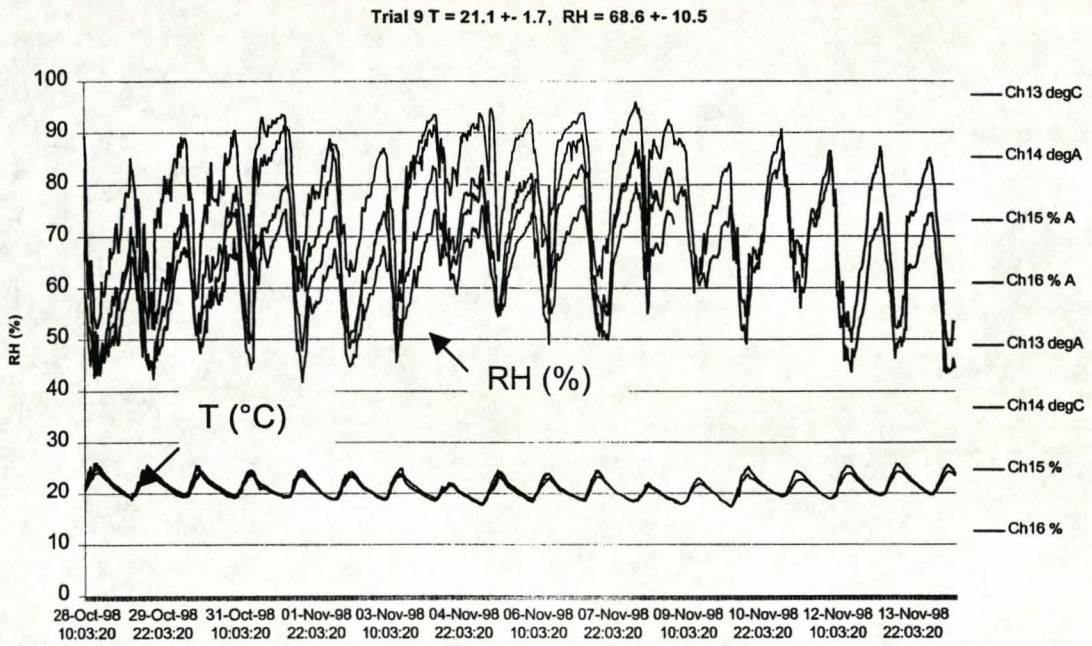
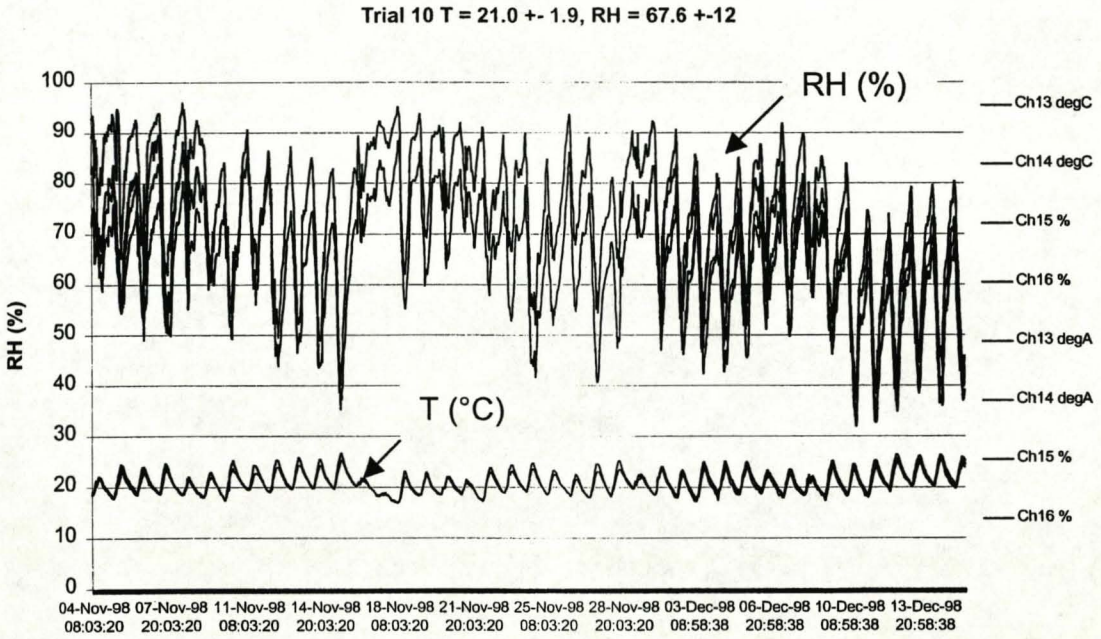
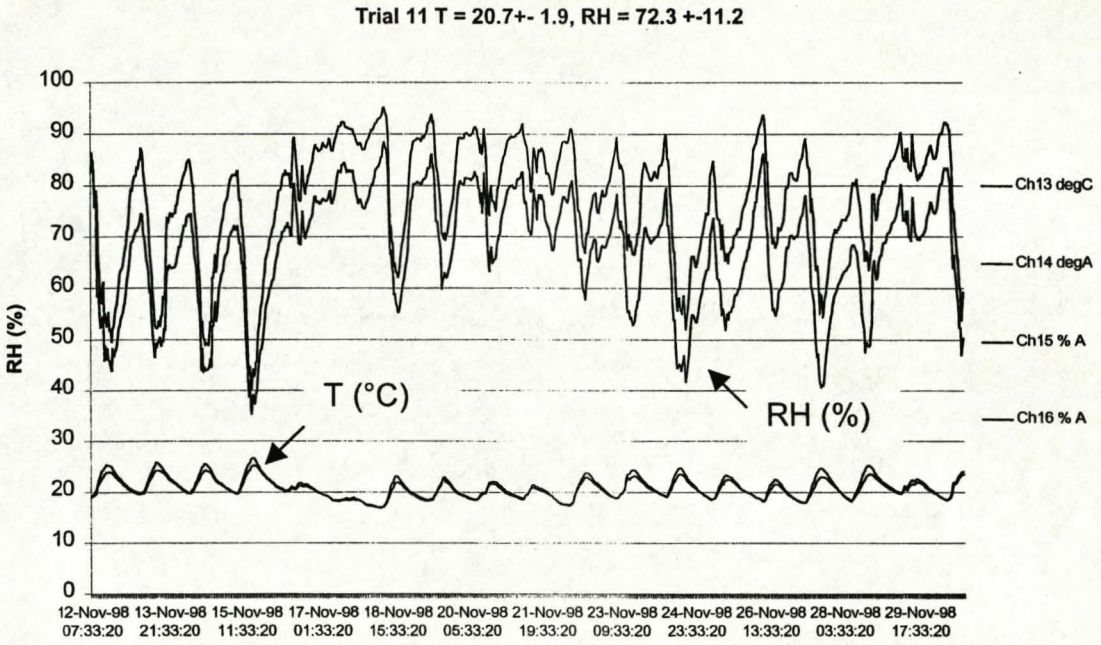


Storage conditions during trial 9.



Storage conditions during trial 10



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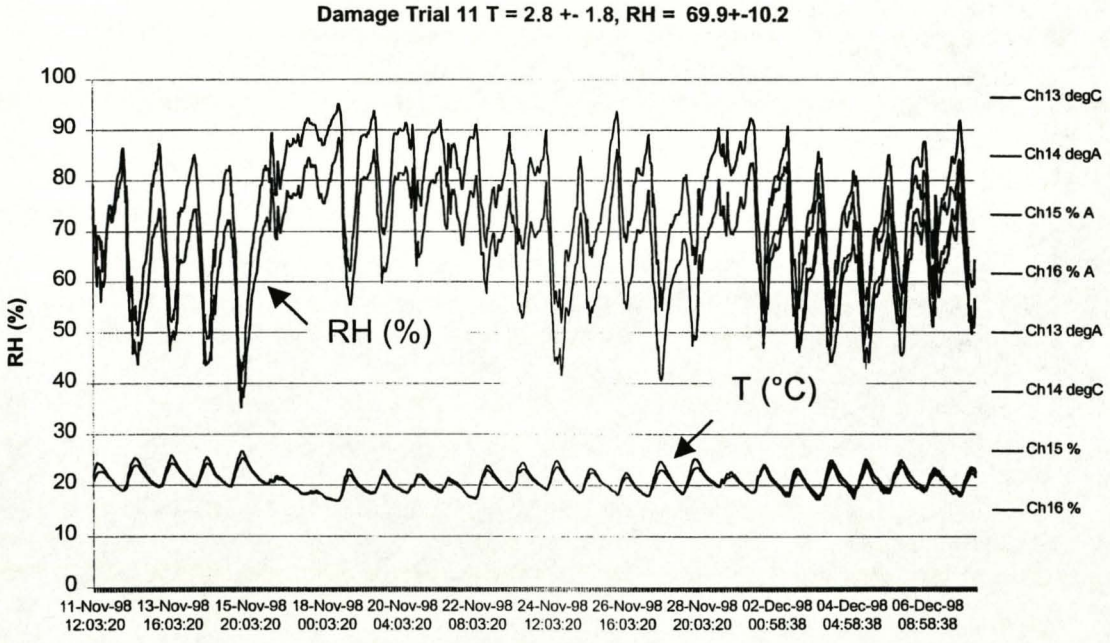
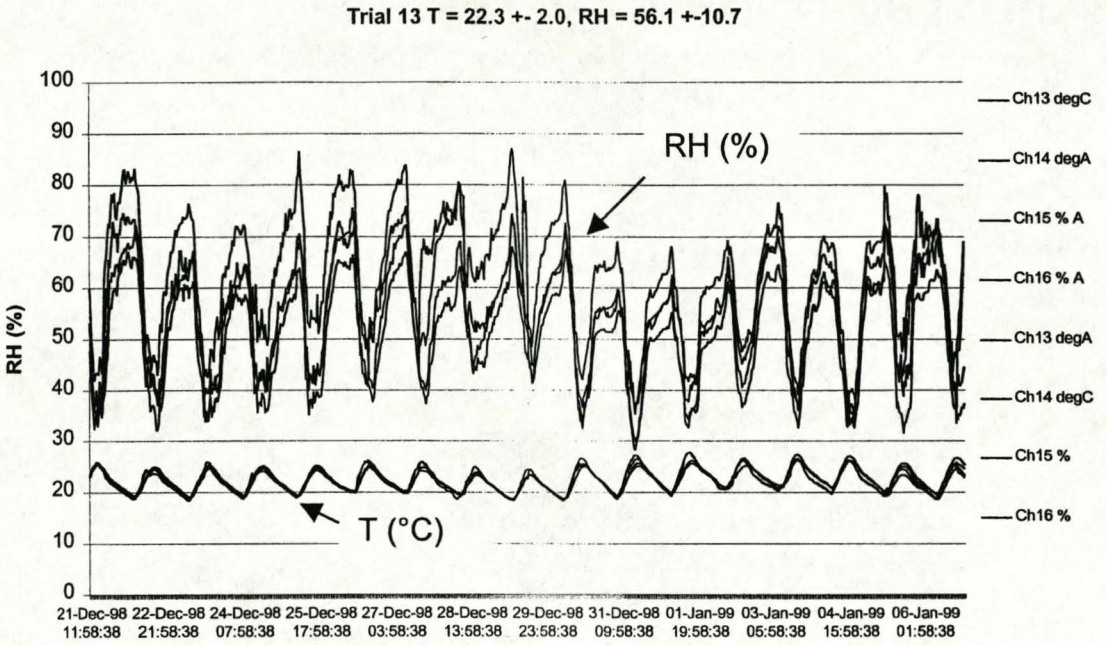
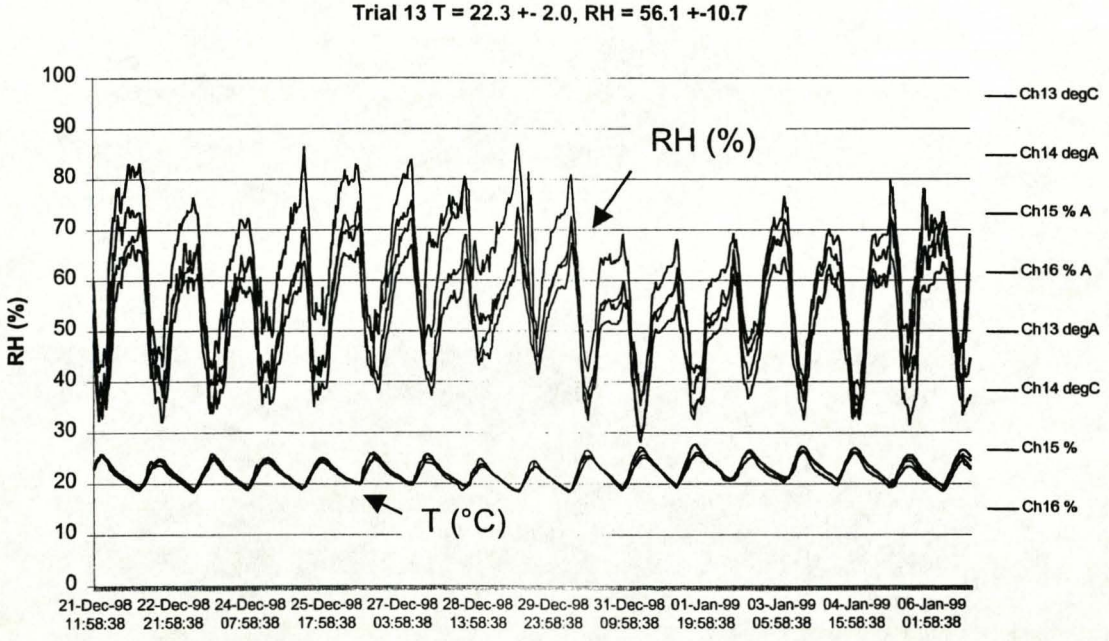


Storage conditions during trial 11b



Storage conditions in trial 12



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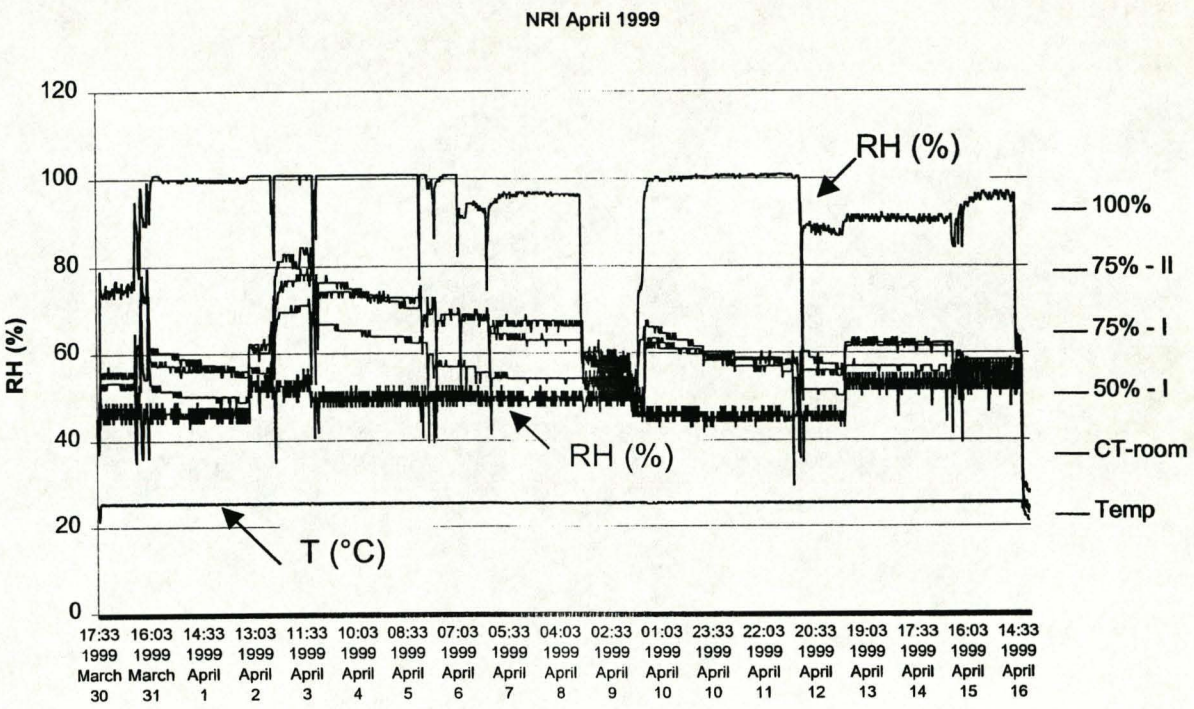

Storage conditions during trial 14

Appendix 2

Transpiration rate through wounds, artificially inflicted with a potato peeler. Each value is the mean of 10 wounds. Storage condition T = 26C, RH = 75%

	TRIAL 9	Time of wound healing					
	Cultivar	**Day 0**	**Day 3**	**Day 6**	**Day 8**	**Day 10**	**Day 13**
Potato	Kihoro	351	36.2	21.1	20.7	19.2	8.7
	Nyayo	365	41.3	24.8	21.2	17.7	10.5
Sweet potato	Zapallo	358	61.1	46.1	23.9	20.4	10.7
	Yan Shu 1	399	85.5	40.9	33.2	34.5	12.6
	BP1-SP-2	359	74.3	61.1	50.9	54.8	18.3
	Caplina	341	85.6	61	55.7	52.8	20.3
	Salyboro	352	98.7	60.2	56.3	43.3	20.5
	Julian	365	87.4	61.3	44.1	70.4	16.8
	KSP 20	393	89	61.8	64.4	55.7	27.2
	Yarada	311	113.7	63.9	71.2	42.6	15.6
	SPK 004	366	93.9	54.8	45.3	61.7	25.9
	Kemb 10	363	86.7	70.8	91.2	54.1	37.7
	Mean sw pot	**360.7**	**87.6**	**58.2**	**53.6**	**49.0**	**20.6**
	Mean potato	**358**	**38.8**	**23**	**21**	**18.5**	**9.6**
	P value	**N.S.**	**P < 0.001**	**P < 0.001**	**P < 0.001**	**P < 0.001**	**P < 0.001**
	LSD		**25.4**	**20.73**	**19.7**	**25.6**	**15.0**
	TRIAL 11	**Time of wound healing**					
	Cultivar	**Day 0**	**Day 3**	**Day 6**	**Day 8**	**Day 10**	**Day 13**
Potato	Kihoro	188.8	37.4	21.3	16.0	16.3	16.6
	Nyayo	200.0	46.3	21.0	17.4	14.2	16.6
Sweet potato	Zapallo	203.0	108.3	33.5	23.9	18.5	23.9
	BP1-SP-2	211.5	119.2	40.2	31.8	23.6	26.6
	Kemb 10	192.8	115.4	55.0	39.6	30.3	38.0
	Yan Shu 1	208.1	120.0	38.6	29.9	23.2	28.2
	Julian	211.7	139.8	49.9	33.2	30.3	32.4
	Salyboro	195.1	129.0	53.0	46.9	30.3	27.6
	Caplina	201.7	138.0	71.8	45.7	36.6	39.1
	KSP 20	225.8	132.8	62.6	41.7	40.9	43.5
	Yarada	211.8	174.3	57.8	34.1	29.1	55.0
	SPK 004	194.6	129.7	62.1	50.1	49.1	81.0
	Mean sw pot	**205.6**	**130.6**	**52.4**	**37.7**	**31.2**	**39.5**
	Mean potato	**194.4**	**41.9**	**21.2**	**16.7**	**15.3**	**16.6**
	P value	**N.S.**	**P < 0.001**	**P < 0.001**	**P < 0.001**	**P < 0.001**	**P < 0.001**
	LSD		**28.7**	**13.6**	**9.56**	**12.5**	**17.9**

Appendix 3

Regression analysis between days and the transpiration rate through artificially inflicted wounds.

Regression analysis	Regression Model	Significance (P value)	% variation explained
Trial 9	Days	< 0.001	53.6
	+ Cult (group factor)	0.315	53.5
	+ Days*Cult	0.974	53.1
Trial 11	Days	< 0.001	65.3
	+ Cult (group factor)	< 0.001	69.2
	+ Days*Cult	= 0.630	69.1

Regression analysis between DM and lignin index of a cultivar.

	Values	P Value	% variance accounted for	Equation
Trial 9	10	0.005	61.1	Y = 1.967 – 0.052 X
Trial 11	10	0.065	28.1	Y = 1.537 – 0.027 X
Trial 12a	8	0.052	41	Y = 2.196 – 0.0623 X
Trial 13a	10	0.008	55.3	Y = 1.756 – 0.045 X

Appendix 1: Assessor recruitment questionnaire

PRIVATE AND CONFIDENTIAL

TASTE PANEL RECRUITMENT QUESTIONNAIRE

PLEASE USE BLOCK CAPITALS TO FILL IN THIS FORM

Please answer the questions as accurately as possible.

You will not be disregarded because you smoke or are unable to consume specific foods, since that area may be of particular interest in our studies.

1. **NAME** _____

2. **ORGANISATION** _____

3. **HOME ADDRESS** _____

4. **If you are asked to take part in our sensory testing panels about 15 minutes of your time would be needed on each visit. However, occasionally during training, between 30 and 60 minutes of your time will be required.**

   Please circle the days of the week when you will not be available.

   MONDAY TUESDAY WEDNESDAY THURSDAY FRIDAY

   Please indicate below other times when you will not be available i.e., holidays, overseas assignments etc.

5. **Do you suffer from health problems which might affect your ability to test certain products?**

   (Examples include: food allergies, diabetes, frequent colds, hayfever, colour blindness, any medication which affects your ability to taste etc.)

   YES ☐

   NO ☐

   If yes please outline the nature of this problem below:

6. Are there any types of food or drink which, for any reason, you woul not be prepared to test?

(Examples include: personal dislike, vegetarian, religious belief

YES ☐

NO ☐

If yes please give details below of the foods/drinks.

7. Do you smoke?

YES ☐

NO ☐

If yes please record below the approximate number of cigarettes you smoke each day.

_____ cigarettes per day

8. Have you ever taken part in any food testing work before?

YES ☐

NO ☐

If yes please outline the work, including the duration of the work, when the work took place and for whom the work was carried out.

Thank you for completing this questionnaire.

Form 2.1 *Brainstorm form for three cultivars*

Tasting Sweet Potato

Name:	Tel extension number:	Date:

In front of you are 3 samples of cooked sweet potao of three different varieties.

Your task is to describe each sample with as much as descriptors as you can think of, that are characteristic of that variety (appaerance, texture and taste). You will get 8 minutes for this.

Orange	Yellow	White

Form 2.2 *Scoring form as used during the brainstorming session*

Appendix 5

Scoring on attributes Sweet Potato

Name:

Tel extension number:

Date:

Please evaluate the three sweet potato samples on the chosen attributes by placing a clear vertical mark on the appropriate position on the lines.
Mark in the following way: the orange sample with 'O'
the yellow samples with 'Y'
the white samples with 'W'

Sample code: . . . . .

Name:

Tel extension number:

Date: **Time:**

Please evaluate the samples.
Take for each sample a new form.
Place a vertical mark on the appropropriate position on the lines.

floury _____ very floury

smooth _____ very smooth

soft _____ very soft

chestnutty _____ very chestnutty

sweet _____ very sweet

fibrous _____ very fibrous

grainy _____ very grainy

moist _____ very moist

discoloration _____ much discoloration